PERMANENT WAY

ROLLING STOCK

AND

TECHNICAL WORKING

OF

RAILWAYS

FOLLOWED BY AN APPENDIX ON WORKS OF ART

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F. J. Bramwell.

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WORKS OF ART.

BY

CH. COUCHE,

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&c, &c.

VOLUME I

WITH AN ATLAS OF 38 PLATES

TRANSLATED FROM THE FRENCH

BY

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TRANSLATOR'S PREFACE.

It is but an act of justice to the distinguished author of this work to say, that some years have elapsed since the translation of the following pages was first undertaken. Various circumstances, over which the author had no control, have led to the delay in the appearance of the English edition; and, in consequence, many of the facts scattered through its pages may now appear somewhat out of date, though when originally written they were fresh and full of interest.

The author has kindly endeavoured to remedy somewhat this fault of the translator's by a few notes in the Supplementary Chapter; and also by some remarks there on "Steel rails," which have now almost superseded Iron ones, though still in considerable use when the pages were first written.

In order to render this edition of further interest to English readers, the translator has added, in the body of the work, some details, as to the arrangement of the many lines of rail which communicate with each other at Clapham Junction, and also as to a few of the earlier forms of the interlocking of points and signals; and, in the supplementary remarks on Steel rails, he has ventured to insert a few of the interesting facts and opinions which have been of late elicited on the subject of this metal, now become of paramount importance in connection with railways.

In conclusion, with respect to the numerous references throughout

the following pages made by the author to works, which originally appeared in England, or to opinions expressed there, the translator must apologize, though he can hardly hold himself responsible, for any errors, particularly in figures, which may have crept in through translation and re-translation of the originals. As it has been quite impossible to verify all these quotations; though, where practicable, this has been done.

Westminster. London. February 1877.

9-13-33

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PERMANENT WAY

ROLLING STOCK

AND

TECHNICAL WORKING

OF

RAILWAYS

FOLLOWED BY AN APPENDIX ON WORKS OF ART

BOOK FIRST.

PERMANENT WAY.

CHAPTER I.

BREADTH OF GAUGE.

§ I. — Principal Lines.

1. The gauge on most lines of railway in Europe, on straights, is $4'\cdot8\frac{1}{2}''$ between the rails.

In France $4'\cdot8\frac{1}{2}''$ and $4'\cdot9''$ have been fixed for the main lines by the government in the terms of their concession. The dimension at first chosen was $4'\cdot11''$ from centre to centre of each rail, so that the actual gauge varied with the breadth of the head of the rail: on some lines this had been slightly increased to afford more play to the line, which experience had shown insufficient to the distance between each pair of wheels upon their axles. Thus, whilst the gauge on the Northern of France Railway is $4'\cdot8\frac{3}{4}''$, on the Mediterranean, Orleans, and Western, of the same country, it is $4'\cdot9''$.

Though this difference is but slight, yet absolute uniformity is to be preferred, both as regards the gauge of the rails, and of the wheels upon their axles;

to this must also be added a certain license in practice in laying the rails, on the Western of France it amounts to 0″·157.

German railway engineers, at their meeting at Dresden in 1865, adopted 4′·8 ½″ as their normal gauge.

The dimension decided upon in France was not the result of a discussion, the elements of which were wanting; it was simply borrowed from England, which had taken the lead in the construction of railways, and had merely copied this from the general gauge of vehicles on ordinary roads.

The imitation was rather a thing of chance, but thanks to the freedom in gauge, which within certain bounds may be said to exist between railways and ordinary vehicles, some years elapsed before this dimension was seriously called in question. Engineers appear to acknowledge, that chance had served them well, or rather that a species of instinct, as to the elements of the question, had led them to this solution.

The construction of the railway from London to Bristol was, however, the signal for a strong reaction.

An engineer, Mr Brunel, whose name had already been rendered famous by his father, and whose own talents and works entitled him to authority, denounced the insufficiency of the gauge adopted, the obstacles of every kind which he considered it placed in the way of the speed of travelling, and of the amount of traffic to be carried; in a word of progress itself. He gained numerous advocates; and the 7′·0″ gauge spread quickly, it reached Bristol, Gloucester, Exeter, Plymouth, and Birmingham.

The 4′·8½″ gauge, meanwhile, also developed itself as if by magic; other lines, such as the Eastern Counties, adopted different widths, which they had the good sense to discard some years later: so that England soon found itself in possession of a magnificent railway system, formed however of discordant elements, for there were no less than seven different gauges, to the great detriment of its industrial and commercial power.

Ireland by its complete isolation was enabled to adopt a gauge of its own, 5′·3″ in width.

All went well, as long as the different systems, and especially the two extreme ones developed themselves, each in their own district, with nothing in common but London for their starting point, and where a connexion between the various lines was not as yet felt to be necessary; it was only when the two gauges met at Gloucester in 1844, that both commerce and industry were aroused. At a meeting of manufacturers at Birmingham, strong protests were raised against the break of gauge, and Mr Wyndham Harding, chairman of the broad gauge line from Bristol to Gloucester, did not shrink from acknowledging,

that the necessity of transhipment of goods was an inconvenience of the greatest importance, " a serious evil, a commercial evil of the first magnitude " (*).

To render transhipment simpler and more expeditious, by performing it on a more extensive scale, large cases, detached from their carriages, were used, and lifted from one gauge to the other. It was with this object, that Mr Brunel, the advocate of the broad gauge, established his first hydraulic presses at the Paddington Station : success did not attend this attempt; and some other experiments, to render the rolling stock available on both gauges, were still less fortunate; so that, apart from the question of transhipment pure and simple, the only remaining solution is that of the third rail, now used on the greater portion of the Great Western Railway, and on the Metropolitan line; a natural solution of the question, but one that is costly, complicated, imperfect, and almost completely excluding trains, which are mixed, or composed of carriages of both gauges; and requiring two inside rails, so that the centres of the carriages, and of the drawing power might coincide.

2. The agitation, which commenced at the Birmingham meeting, spread to Parliament; Mr Cobden in the House of Commons, and Lord Dalhousie in the House of Lords, demanded a commission of inquiry upon the subject; it was granted in 1845, and composed of Professor Airy, Astronomer Royal, Professor Barlow of the Woolwich Academy, and Col. Smith, Royal Engineers. This inquiry, precise, clear, and without wandering from its subject, as these inquiries are carried out in England, placed the two systems face to face. The narrow gauge came forth triumphant from this severe examination.

While allowing, that its rival granted greater facilities in the construction of engines, the commission agreed, that the $4'{\cdot}8\frac{1}{2}''$ gauge in no way precluded improvement therein, though it rendered it a little more difficult; yet that art could easily surmount these difficulties, as had been proved by the advocates of the narrow gauge system, by means of the results already obtained. It also acknowledged, that the narrow gauge was more in accordance with the ordinary conditions of goods traffic, and that the capacity of its waggons was better in keeping with mercantile wants, as well as with the utilization of the rolling stock, than those of the broad gauge.

(*) In a report made in conjunction with Mr J. Mc Connell, he again defines the break of gauge to be " a commercial evil, which would alone neutralize half the benefits of the railway system ".

3. The length of time, which has elapsed since this remarkable inquiry took place, has not in any way diminished the weight of the argument, which then decided the question in favour of the narrow gauge: even fresh ones have been added. Mechanical Engineers, by placing the whole of the machinery on the outside of the engines, as is often the case, as well as the apparatus for feeding, and for distributing the water, have relieved the narrow gauge from one of its principal objections: experience also has shown the worth of another grievance, viz., the pretended insufficiency of this gauge for engine-wheels of large diameter. Apart from Crampton's locomotives, where the height of the centre of gravity is independent of the diameter of the driving wheels, 6'.6", and in some cases up to 10'·0", are of common construction in England, despite the pretended limit of 5'·0".

Some reduction in the radii of curves has become indispensable, in consequence of the more difficult nature of country, which it is now necessary to pass through; and the limit to this reduction evidently becomes smaller, as the gauge is narrower.

Mr Brunel himself was obliged to acknowledge, that the narrow gauge was better fitted for lines with numerous curves; and, though he succeeded, yet not without difficulty, in getting the Great Western Railway laid with the 7'·0" gauge, nevertheless the Taff Vale line was constructed with the 4'·8½" one.

4. No special virtue can be claimed as belonging to the dimension 4'·8½"; indeed there may be some advantages, and but few inconveniences, arising from a slight increase upon it: still there is no really serious objection which can be raised to it.

France, which for some time was rather backward in commencing the railway system, in the hope of profiting by the progress of her neighbours, as well as by their faults, at length ended by doing what she might have done several years sooner, viz., she simply followed the example of the first railways constructed in England.

So quickly however did she make up the lost time, that she precluded any remedy for her error, had fresh facts proved she was wrong; the course however which she pursued is in no way to be regretted.

5. Of those European states which have adopted a wider gauge, some have now reverted to the ordinary one, others still adhere to their choice.

Doubtless this determination, on the part of the former, has been caused,

less by a tardy conviction of the advantages of the narrow gauge, than by a wish to escape from the isolated position in which they were placed.

The Grand-Duchy of Baden with its 5'·2" gauge, and later on Holland, with the 7'·0" one, found themselves excluded from traffic, which could easily avoid their territories, in themselves of but small extent.

If on the other hand extensive countries such as Russia, and Spain, have fixed upon a larger dimension, it has been principally, if not entirely, on grounds quite apart from commercial or scientific views.

The object in both cases has been to differ from the general continental system; and it certainly was better, that this difference should be by an augmentation, rather than by a diminution in breadth of way.

In Russia this increase is merely $3\frac{1}{4}$ inches (5 feet English being their gauge); a mere trifle in the eyes of the advocates of broad gauges.

Spain however went farther; 5'·6" (6 feet Spanish) is the gauge; but as the rolling stock is built on exactly the same principle, as that of the rest of the Continent, she thus showed her unwillingness to be relieved from the pretended trammels of the narrow gauge.

The most powerful Spanish locomotives, of eight wheels coupled, have no greater power, than those in use elsewhere; the maximum freight of their four-wheeled waggons is only 10 tons: similarly 24 is the number of seats in the 1st class passenger carriages, 40 in the second, and 50 in the third. On the Saragossa, and on the Alicante lines, the carriages are wider, and in the 1st class an attempt was made to turn this to account by adding a fifth seat, but it failed through the opposition of the travellers themselves; so that the only advantage which ensues is the greater width of each seat; a convenience no doubt, but one that does not arise from the increased gauge.

In France it is not the narrowness of the gauge, which prevents this increased width in the rolling stock; for the carriages might easily be made to project beyond the rails, more than they do at present; but it is the want of space between the lines, and the nearness of the sides of the tunnels.

6. A difference of gauge exists also on the other side of the Ocean, without however there being any serious cause for it.

The celebrated Niagara Suspension Bridge connecting the United States and the Canadian Railway systems, carries 3 rails, corresponding to two different gauges. Altogether the United States lines have six different gauges varying beween 5'·11" (the Erie railway), and 4'·$8\frac{1}{2}$"; this last being however nearly the general one.

In Canada there are two 5'·6" and 4'·$8\frac{1}{2}$": in India 5'·6" (from centre to

centre of the rails) : in Chili the Valparaiso to Santiago Railway also has a 5′·6″ gauge : in Brazil this dimension was first used; it has since been replaced by a 5′·3″ gauge; it is difficult to understand the utility of this diminution of three inches.

It is easy to conceive, how Engineers in constructing the Australian lines should have chosen a gauge somewhat broader than the 4′·8½″ one; but it is singular that the want of continuity, the defects of which had been so clearly shown in the mother country, should again be reproduced in one of its most important colonies. In New South Wales the gauge is 4′·8½″; whereas in Victoria it is 5′·3″; this may be regretted, when the Sydney and Melbourne lines join, and possibly the day may not be far distant.

§ II. — Secondary Lines.

7. Though the gauge for the main system of railways in France has long been definitively settled, yet by no means is this the case for secondary ones, or lines of local interest.

The question has often been raised of late, and it is still an open one; but it is no longer one of augmentation; for the contest now wages only between the existing gauge and a narrower one.

In Prussia likewise, this matter has been under serious consideration.

The government argued, that there ought to be reciprocal communication between the primary, and the secondary systems of railways : and German railway Engineers at their Congress at Dresden were unanimously of the same view.

In laying down this principle of uniformity of gauge, the right to depart from it, in certain fixed cases, must doubtless be reserved : these exceptions however should be justified by local circumstances, by the nature and paucity of probable traffic, or by the importance of the economy to be effected, by the proposed reduction of gauge.

8. In France the commission of inquiry, formed in 1861, laid down the opposite principle (*) : it adhered firmly to the principle of transhipment; but it took into consideration merely the price of porterage, properly so called; *i.e.* about 4d per ton on the average.

This figure cannot be neglected; the less so that, owing to the very object of these lines, it would press heavily upon those articles especially, which are

(*) "Inquiry on the working and construction of railways", page 144. — 1863.

mostly of small value, such as minerals, manures, building materials, and coal, and which are carried only for short distances; besides it far from represents the pecuniary consequences arising from break of carriage, overlooking the additional expenses caused by the interruption, the extra size of depots, the number of waggons, their length of time unemployed, both when full and empty, and consequently of the staff required : and it omits altogether the time lost by the materials in their transit.

If, as some suppose, it is possible so far to push economy in the construction of these secondary lines, as to render them unable to support the rolling stock of the more important ones, then might this systematic reduction of gauge be justified. But it is by steam power that these lines are to be worked, where the engines, having to draw trains of considerable weight, and often on sharp inclines, would be heavier than the most heavily laden waggons of the principal lines : and a permanent way, sufficiently solid to support the former, will carry the latter all the more easily, as, at even weights, a locomotive does more harm to the permanent way than a waggon does.

A secondary system of a narrower gauge, intermingled with the main system, might some day engender a position analogous to that, which took place, when England was threatened by a simultaneous advance of the rival gauges.

9. India offers a very recent example of the inconvenience, which generally arises from the want of continuity between primary and secondary lines; and also of the determination with which the English, once the fault was acknowledged, set to work to repair it.

The principal Indian railway companies arranged to adopt a gauge somewhat broader, than that used in England : 5′·3″ was the dimension fixed. One however of the secondary lines, the Indian Branch Railway, had been made with a gauge of only 4 feet; the whole of the rest of the system was laid down to the 5′·6″ gauge, despite the economy with which this had been constructed, which was somewhat due no doubt to its narrowness of gauge.

The portion above mentioned, though it has been but two years and a half open to traffic, is about being altered to the larger dimension.

The difficulties of transhipment alone did not cause the company to make so radical a change; the unforeseen development of traffic, and the necessity of placing everything in accordance with this increase, by which they hoped to be reimbursed for necessary extra expenses required by the change, also led to it.

Similar circumstances may arise elsewhere, and therefore this lesson, though coming from a distance, ought not to be lost.

10. Again let us repeat that it is highly dangerous to make a system absolute, and without exception; for surely there are many lines which, being, completely excluded from general traffic, ought to limit their operations to purely local wants; whose future it is of absolute importance to estimate truly, and where economy ought to be pushed to its utmost limit.

We may here quote some examples of these unpretentious lines, and to which we shall not again revert in the course of this work.

Of these one of the most remarkable, on account of the narrowness of its gauge, 2′·0″, is the Festiniog Railway, from Dinas to Port Madoc, in North Wales.

More than thirty years ago it was constructed, with very great economy, to carry slates from the quarries round Dinas to the neighbouring ports, and to bring back coals.

Its length is 13 miles; it has gradients as steep as 1 in 60; and some curves have a radius of only 2 chains: the cant of the outer rail, calculated for a speed of 8 miles per hour, is $2\frac{1}{2}''$.

Till 1863 the haulage on the up journey was performed by horses, which were brought back in a waggon specially constructed for the purpose; as the traffic increased, it became desirable to substitute locomotives for the horses; and Mr England has succeeded in making engines, which travel without any difficulty on this narrow line, at the rate of 10 miles per hour, reduced to 6 at the sharpest curves only.

This being successfully accomplished, a still further advance was desired, and one which the originators had never even thought of; viz., of establishing a passenger service: at first it was done gratuitously, as an experiment; now however the system works regularly; there are five trains each way every day, Sundays excepted. When descending, which takes place by gravity, the train is divided into three separate portions: first the waggons, full and empty; then at a short distance the locomotive; and then again at a short distance the passenger train.

The rail, double-headed, weighs 30 lbs. per yard, and is fastened down by cast-iron chairs to larch sleepers. The engines are 4 wheels coupled, of 2′·0″ diameter, the axles being 5′·0″ apart; outside cylinders 8″ in diameter, and 12″ stroke; and carrying a portion of their water in tanks arranged round the boiler; the remainder being borne by a small 4 wheeled tender: the locomotive in water weighs $7\frac{1}{2}$ tons; on the upward journey it draws a total load of 50 tons. exclusive of tender and of itself, at the rate of 10 miles per hour.

The passengers carriages have each four wheels, 1′·6″ in diameter, 4′·0″ between the axles; they are 10′·0″ long, and 6′·3″ wide.

A longitudinal division separates the two benches, affording room for 12 passengers, sitting back to back.

The load is thus rendered central, and more stability acquired.

The height of the floor above the rails is only 9″; there is a door at each end, and but one buffer. The width of the carriages is limited, not only, by the very small distance between the rails, but also by the vicinity of obstacles alongside of the line.

The passenger service on the Festiniog line is at present merely tolerated by law; for $4'\cdot 8\frac{1}{2}''$ is still the minimum gauge allowed for the conveyance of passengers; perhaps this example may cause the permission to be extended.

It is on the ordinary gauge, that those tramways in Scotland have been laid down, the cheapness of construction and of working of which, has lately been much praised.

Had the originators of the Festiniog line foreseen the day, when locomotives and passengers would travel on their line, assuredly they would not have adopted a $2'\cdot 0''$ gauge: yet this diminutive gauge is sufficient, and this is the interesting part of this example; for it affords a railway able to meet the unforeseen requirements of traffic, at a suitable rate of travelling, and with complete security.

Before condemning a line to isolation, and thus pledging its future, its circumstances ought doubtless to be fully considered; but, when isolation is in the natural order of things, and taken as such whether right or wrong, then as much advantage as possible ought to be obtained by a reduction of gauge, especially in hilly countries, through a corresponding reduction in the radii of the curves.

11. One of the oldest lines on a narrow gauge is that from Antwerp to Ghent in Belgium; terminating opposite to Antwerp at the Tête-de-Flandres, and separated from it by the Scheldt, it is thus cut off at one of its extremities from the Belgian system; and had therefore but little to lose by complete isolation, which gave it the freedom and power to be constructed in a moderate and unpretentious manner, in keeping with the interests it was intended to serve.

In it the engineer, Mr de Ridder, wished to give an example how, even with a gauge only two thirds of the ordinary one ($3'\cdot 3''$), a railway was still a useful implement, and one sufficiently powerful to supply the moderate requirements of both speed and traffic : and in truth this justice must be done to him, that nearly five and twenty years ago, he succeeded in framing out of the different elements, a complete system, one full of ingenious details, and also of real progress: as for example the consumption of coal

by the engines, at a time when such a thing was considered almost impossible. This is the only example in Belgium of a narrow gauge line carrying passengers.

12. Mr Thirion, directing engineer of the works of the Orleans Railway, and Mr Bertera, engineer in chief of mines, have published (*) some interesting information respecting a small branch line, $4\frac{1}{2}$ miles long, which joins the Mondalzac mines with the Salles-la-Source Station, in the department of Aveyron.

The line is 3'·7" in the clear, the rails are inverted T, fished, weigh 33 lbs. per yard, and are supported on oak sleepers, 2'·6" apart; the waggons carry $3\frac{3}{4}$ tons; the locomotives have 2 pairs of wheels coupled, 4'·7" between the axles, weigh a little more than 9 tons, and travel easily round curves of 2 and 3 chains radius.

The writers of the pamphlet have made use of the discussion of the economical and scientific principles, developed in the construction and maintenance of this little line, as a starting point for a more general inquiry upon departmental lines of railway. They argue that "lines of small gauge are destined to be of service in many cases, where a large line is impossible: that it is desirable the parties interested therein should have the choice thereof; but, that the absolute power to authorize, or reject their selection, ought to rest with the directors of the main line."

Stated thus in general terms, this opinion appears well founded.

For surely, between a line constructed on the principle of a main line, and no railway at all, there must be some mean.

Is it however advisable, in deciding this question of a narrower gauge, to accept the dimension proposed by them of 4'·0" from centre to centre of the rail? This is the width they advocate for the construction of a railway in the valley of the Saule, (**) as well as a 42 lbs rail "in order to allow greater power to the engines, than on the Mondalzac line."

Is this reduction of from 5'·0" to 4'·0", or of one fifth only, really worth the while? a 42 lbs. rail will assuredly carry the waggons of a main line.

Why therefore sacrifice continuity of gauge, for the sake of 12"? which would make but little difference in the cost of land and of rolling stock; in weight of rail there is no saving whatever, and as to curves the advantage would, either

(*) Observations on the proposed law of departmental railways. Paris, 1865, Dunod.

(**) Observations on the proposed law of departmental railways (Pamphlet above quoted), p. 22.

be so small, as to be scarcely perceptible or, if appreciable in consequence of the hilly nature of the country, would only be an argument in favour of a still further reduction, in order to effect a greater economy.

Their argument, in favour of a comparatively wide gauge, seems devoid of foundation; for, in engines of low speed, and consequently with wheels of small diameter, the amount of power is, within certain limits, independent of the breadth of way, as the width of the boiler may considerably exceed that between the wheels. We shall revert to this point in treating of locomotives.

13. In Norway there are two passenger lines, on a narrow gauge of 3′·6″; one from Grundsett to Hamar, 24 miles long, with inclines of 1 in 70, and curves of 15 chains radius: the other 30 miles in length from Trondhjem to Stören, with inclines of 1 in 42, and curves having a radius of only $10\frac{1}{2}$ chains; the engines weigh about 14 tons.

The Norwegian government appears inclined to adopt this same gauge for the rest of the railways in that country.

14. To lay rails along the sides of the roads is no new idea; in general however this is difficult to do, owing to the frequent bends, which they take, and to the steep inclines, which they present: and hence but few examples exist.

It is possible however that more may be laid down; in which case a narrow gauge may not only be advisable, but even be rendered necessary on account of the smallness of the strip of land available.

Thus, in the temporary railway over the Mont Cenis, 3′·7″ is the width selected, and laid on the central rail principle; a method, which will be treated of later on: the sharpness of the radii of several curves was in this case an argument in favour of a narrower gauge.

In the Broelthal, in Westphalia, there is a small line laid for a portion of its length on the main road, and interesting, not only on this account, but also by reason of its narrow gauge.

It goes from Hennef, a station on the Cologne and Giessen Railway, to Ruppichterof, a distance of 12 miles; between Waarth and Ruppichterof the rails are laid on the roadside : at first it was feared this might cause some accidents; but this was groundless, as the horses now travel alongside of the trains without being frightened.

It is only 2′·8″ wide, in consequence of the narrowness of the road, and is laid on sleepers, 4′·0″ long, and 1′·8″ apart : the depth of ballast is only 8′ ; the rails are inverted ⊤, weigh 21 lbs. per yard, are fished, and with joint plates. The steepest gradient is 1 in 80, and near the Bridge over the Sieg at Allner

there is a curve of only $2\frac{1}{2}$ chains radius; tank engines are used, of 6 wheels coupled, with cylinders 11″ in diameter, and 13″ stroke; in water they weigh 12 tons, equally distributed over the three pair of wheels.

Each waggon, weighing $4\frac{1}{2}$ tons, carries 5 tons; the axles and tires are of puddled steel; 4′·8″ was originally the outside width of the waggons, but lately it has been increased to 6′·2″, or about two and a half times the width of the gauge : the price of carriage by rail is only one third of that by road.

Failure was predicted for this line; a fate similar to that of several other lines of narrow gauge in Silesia : these however were expensively made, and the hilly nature of the country renders them costly to work; whereas the above quoted little line was very economical in construction, and it has the advantage of a considerable fall in the direction of its principal traffic.

15. If cheap railways, with a narrow gauge, are suited to little favoured districts of countries, which themselves are rich and full of industry, doubtless they are fitted for distant lands, still in nature's garb, and to which civilization is only now extending her fertilizing, and beneficial influence.

In countries such as these, where large mineral districts keep down, and check the progress of industry in general, and where the face of the land is covered only with forests and vast grazing tracts, yielding but wood and herds of cattle, it is impossible, that any considerable amount of capital can, at least for some time to come, be rendered remunerative by means only of the present traffic.

Rapidity of travelling is therefore in such cases, as useless as it is costly; and railways simple in their construction are the best means of civilizing these primitive climes; for to the advantage derived from economy in cost, they add that of rapidity of construction.

Such is the case with the railways, now being constructed in Queensland, that vast tract at the North Eastern corner of Australia, which extends from New South Wales to Torres Straits; and which has Brisbane for its capital.

The following details are taken from the report published in 1865 by Mr Fitzgibbon, engineer in chief of those lines. The object was to place at a small cost the interior in communication with the coast, for the conveyance of cattle seawards, and inland of articles of consumption to a population widely scattered, and not likely for some time to come to be grouped together in any important centres,

From each port a line was to penetrate, more or less into the interior. The line, with a 3′·6″ gauge, was to allow with ease a daily traffic of 200 tons of

goods, and 400 passengers each way, at a rate of from 15 to 20 miles per hour. According to Mr Fitzgibbon the cost under ordinary circumstances would not exceed £ 4,000 per mile, and in more difficult parts £ 6,500 (*).

The cost, he believes, in the mountainous parts, would have been much greater with the 4'·8½" gauge : he considers a curve of 18 chains with the 3'·6" gauge equivalent to one of 24 chains on the ordinary one : and estimates the saving at at least two thirds in the more difficult portions, as by the substitution of the former curve for the latter, many cuttings, tunnels, and viaducts have been avoided; and this without rendering the working of the line any more difficult.

16. Should good and ample reasons present themselves in any case for a reduced gauge, adopt it; but let these be sufficient to make it worth the while: for instance, should 3'·0" appear too narrow a gauge, it is far better to adopt the ordinary 4'·8½", than to incur all the disadvantages arising from a reduction, without really deriving any benefit from it.

The former are certain, the latter becomes insignificant in proportion as the diminution is small : either reduce considerably, or not at all.

Except in the case of constant and permanent isolation, either by position, or by choice, and which does not enter into this discussion, it is difficult to justify a gauge of 4'·0".

(*) Mr C. D. Fox, in his paper on the "Queensland railways" lately read before the Institution of Civil Engineers in London, mentions £ 6,000, as the minimum cost per mile. — Translator.

CHAPTER II.

FORM OF RAILS ON NON-CONTINUOUS SUPPORTS.

§ I. — General discussion of form. Comparison of various types, double-headed, single T, inverted T.

17. Like many other practical problems which appear very simple, the construction of a permanent way, well fitted for the duties it has to perform, is in reality a very difficult one to solve.

As the conditions, in which its various elements are placed, cannot be contained within any strict definition, it is impossible to estimate with precision, the intensity of the mechanical action, to which they are subjected; a long experience alone of any system can pronounce upon its merit, unless it is a decidedly bad one.

Hence it is that, up to a certain point, engineers, though convinced of the imperfections of ordinary methods, should have for a long time preferred adhering to them, to trying lengthy experiments, ending perhaps in worse instead of better.

In France until of late years, excepting some few unsuccessful experiments, it was the universal custom to imitate that system, almost exclusively in use in England, despite its many drawbacks : and nearly all improvements were confined to the increase of weight of metal; a method costly, yet insufficient.

It is not, for example, merely by increasing the weight of the axles, that their breakage has been prevented, even now to a most satisfactory degree; but principally by improvements in manufacture and in form : the addition of several pounds to the weight of each axle is not a matter of much importance; not so however with a constantly recurring item, such as each length of rail.

Everything in connexion with permanent way has in Germany been made a study of, with a special predilection, and with greater method and connection, than anywhere else; not even excepting England.

In railway matters one is disposed at first sight to seek for models rather in England, than in Germany : nevertheless, in England the permanent way most generally in use, the chair system, is but the result of imitation : it is adhered to not on account of its merits, but because contractors, and large

iron foundries, having got into the way of making and using it, find it better to continue to do so, than to change it : in Germany on the contrary the uniformity , which there exists, more generally still, is the result of long and conflicting experience, extending over a wide field, and a considerable length of time.

It is astonishing, considering that the railway system has been in complete working order for upwards of thirty years, with scarcely more than three or four types of permanent way in vogue, ever since the commencement, that experience has not long ago settled the disputed point; their respective efficiency.

That it is so, is mainly due, in France especially, to their having but lately adopted the only truly conclusive method of comparison, viz., by laying down the different types on the same line : again circumstances were for a long time unfavourable to a complete comparison of the practical worth, and economy of the different rivals. A comparison of this kind demands a fixed permanent condition during a certain length of time; and this could not be carried out. Fresh elements were constantly being introduced, through the augmentation of speed, with its attendant requirements, and the ever increasing weight of locomotives : the rails, becoming too light for their burden, were taken up before their time, to maintain more or less the equilibrium, which must of a necessity exist between the permanent way, the rolling stock, and the speed of travelling : the recent date of several important lines, as well as successive transformation of older ones, explains up to a certain point this lengthened absence of any fixed ideas on all, that is connected with permanent way ; and why we still are reduced to conjecture, or little better, to estimate the depreciation for a given period of its various elements, viz., permanent way, rolling stock, rate of travelling, and traffic carried.

" Up to the present time any data relating to the important, and complex " question of wear of permanent way have been very untrustworthy. Now " we are able to fix, if not with exactness, at least approximately, the duration " of the various parts of the permanent way, placed as it is under different " conditions on the several portions of our system ; and we trust that the time " will shortly come, when we may fix exactly the amount of renewals yearly " caused by depreciation, and so avoid those sudden variations on this head, " which the present method causes."

So said the report presented in April 1866, at the general meeting of the shareholders of the Paris and the Mediterranean lines.

The question of length of durability, the solution of which only just begins to be foreshadowed, forms a necessary element in the complete comparison of

the different methods : so long as it remains unsolved, the partisans of any one of them may claim an advantage on this head, without proving their right to do so, and also without the possibility of their being proved in the wrong.

If a type of permanent way be found, which is at the same time more economical in its first cost, safer, and easier of maintenance, — advantages quite sufficient of themselves to secure it the preference—doubtless to these may be added, a smaller amount of wear in its materials.

As to the form of rail, the complete unanimity, to which German engineers have been led by means of discussions, always based upon actual observations, ought to constitute a strong presumption in favour of a method, which has centred round it the favourable opinion of almost all of them.

After trying in every form the double-headed rail, the single T, the bridge-rail, and the American or Vignoles rail, first on longitudinal, and then on cross sleepers, they have almost unanimously adopted the last named combination : one must be very incredulous in matter of proof, not to perceive therein, at least a great probability in favour of the superiority of the Vignoles rail.

In spite of the experience, obtained at considerable trouble, and almost under their very eyes, French engineers had at first, in the construction of their railways, done little else than go round in a circle, leaving the double headed rail for the single, or vice versâ; increasing, or diminishing, the breadth of the head, or the thickness of the web; varying in fact the small details almost as if by chance; resulting, especially in chairs, in an incredible variety of forms, between which, even the most skilful would have found it difficult, to make a choice based upon sound reason : it would forsooth have been better to have paused in the improvement of the chair, and to have inquired into the cause of its existence.

Now, however, the question has taken a decisive step; the results, arising from its extensive application on the Northern of France line, cannot but be taken as evidence thereof. If some engineers still persist in preferring the double-headed rail, at least the Vignoles rail can no longer be stigmatised as defective, unsteady, unfit for high speeds, and in a word suited at best, but for secondary lines. This rail will henceforth be adopted exclusively on two of the main trunk railways in France, the Northern, and the Eastern; on others too it plays a very considerable part : the Orleans (central section); Mediterranean, Paris and Lyons (by the Bourbonnais), Toulon and Nice, etc., etc.; and the time is doubtless not far distant, when the chair-rail will have disappeared altogether.

A single inquiry made in 1853 into the German railway system, left me no doubt upon this head (*).

Its opponents are now daily diminishing; twelve years ago in France the chair rail had an enormous majority, amounting almost to unanimity; now its advocates become each day fewer in numbers: still that minority, which remains true to it, is fully convinced of its advantages; talents and ability they certainly possess, and therefore their opinion is entitled to be discussed.

18. *Comparative resistance to pressure of the chair rail, and of the Vignoles rail.*

Rails placed on non-continuous supports are subject to pressures tending, 1° to cause them to slip outwards; 2° to crush them, and to destroy their upper face; 3° to bend, and to break them.

The general form of the rail is a consequence of this latter consideration; as with all solid bodies weighted with a transverse load, its section ought to be founded upon that of a hollow rectangle, or a double **T**; this concentration of metal towards the extremities of the section, though it may not tend to distribute the strains exercised by the wheels, yet it affords a means of strengthening the very small area, upon which these strains are necessarily brought to bear.

As to the stability of rotation, it may either be included amongst those conditions, which must be fulfilled by the rail, and hence must be an element in the determination of its form; or else this latter may be decided upon, irrespective of its stability, which duty is left to the intermediate bearers. In the first case, the form of the lower part of the rail is dependent upon the double condition, of ensuring in itself sufficient stability on its bearings, and of distributing the metal in a manner favorable to resist transverse strain: in the latter its form has but one condition to fulfil; viz., that the distribution of the metal shall be such, as to resist the wearing action of the wheels, as well as transverse strain.

The Vignoles, or inverted **T** rail, on the one part, and the double-headed rail on the other, are the results of the above two ways of considering the question: when it is looked at in the latter light, either the single or the double headed form may be adopted, according to what may be considered the most advantageous conditions for resistance to transverse strain, as well as to wearing action; or again in proportion to the degree of importance attributed relatively to each.

(*) The remarks made at that time were published in a work entitled "German Railways, their works of art and permanent way".

This having for some time been out of print, I here reproduce the facts which still are of interest, and those remarks which have since been confirmed by experience.

19. *Resistance. Description of apparatus.*

We shall first consider the side of the question, which has been most studied; viz., resistance to transverse strain.

The inquiries of the Prussian Government, made in 1851 under the direction of M[r] Weishaupt, are still the most perfect which exist on this matter.

In that country the superiority of the Vignoles rail has, since 1849, scarcely ever been disputed on the score of economy of first cost, of facility of maintenance, and on the several accounts of solidity and safety to the permanent way : it was only feared that these advantages were purchased at the cost of a loss of transverse resistance on the part of the rail. Though the government had already after a lengthened inquiry adopted this form for the Eastern Railway (from Berlin to Kœnisberg), which was only departed from on the section from Dirschau to Kœnigsberg, yet in 1849 it was again determined to study the question afresh.

The engineers of the state railways, and of those lines, to which concessions had been granted, were consulted upon the subject; and the result was again a considerable majority in favour of the type previonsly selected : nevertheless the government, in consideration that many had abstained from voting, and that others still persisted in their doubts, ordered an additional inquiry accompanied by special experiments upon the disputed point, viz., transverse resistance.

They were carried out at Berlin at the manufactory of M[r] Börsig Senior, who has since been taken away from that branch of art, in which he had acquired a name so justly renowned.

It is no loss of time to repeat the principal results; for, by the precision and power of the apparatus used, and the number and methodical character of the experiments, this inquiry ranks among the first of its kind (*) (Plate I, fig. 1 to 4).

The portion of rail, about to be tested, was loaded by means of a cast iron lever; it rested on two steel blades $\alpha\alpha$, $3'\cdot1''$ apart, and was fixed on two cast iron supports *f*, *f*, fig. 3 : this lever, moveable round the edge *a*, *a*, had fixed into it at $\frac{1}{10}$ of its length a small piece of steel, which pressed on the rail. In inquiries of this kind it is absolutely indispensable, that the pressure be always exercised with rigorous exactness in one direction, viz., vertically; for without this the results obtained could not be compared with each other : it is therefore necessary that the lever should descend in a line parallel to itself,

(*) See, " Untersuchungen über die Tragfähigkeit verschiedener Eisenbahn-schienen " by T[r] Weishaupt. Berlin, 1852.

according as the rail yields, *i. e.* that the edge *a*, *a*, must drop a distance similar to, and simultaneously with, the deflection of the rail.

At first the bent end of the lever was merely inserted in the head of a bar with a screw, *v*, turned on its lower portion; and to which a longitudinal movement was imparted by means of a socket and collar, working in an endless screw with a handle attached. When not in use, the lever was supported at one end by the pin, *d*, and suspended at the other to the hook, *e*; in order to load it gradually, the portion, *f*, was raised by means of a pulley, and again lowered by the same means: small deflections, magnified ten times, were read on a scale divided to tenths of an inch; larger ones being taken directly off a scale by means of a vernier; the load was successively increased till breakage took place; after each augmentation the deflection due to the weight, as well as the permanent set, were noted.

When the load exceeded a certain limit, varying according to the nature of the metal, it became very difficult, even in spite of the reaction of the axis, *a*, of the lever, to counteract the lateral tendency of the rail to turn over: as the screw, *v*, having nothing in its upper part to guide it, yielded but too easily to this tendency.

After many trials, the apparatus was at length completed, by the addition of the two cheeks F, F, (fig. 2, 3 and 4), forming a slide for the bar of the screw, *v*, to work in, and thus preventing its turning over : this sufficed, where the metal experimented upon was of a hard nature; but in the softer kinds a disposition to bend again showed itself, to counteract which it was necessary to reverse the position of the ends of the rail. A defect in the arrangement of the axis of the lever was also shown by experience to exist; when the dish, *p*, was lowered to receive the weight, the small piece of steel, *h*, did not always, after the balancing movement of the lever, return exactly to the middle of the edge, *a*, *a*; which could only again be obtained by guess-work, moving it backwards and forwards; and similarly was the original relation between the two arms of the lever reestablished.

This difficulty was got over by keeping the small piece, *h*, constantly pressed against the edge, unless when the lever was working; a moveable pin, *d*, with a counterpoise P, being substituted for the fixed pin, *d*, and so urging it always upwards : to overcome this difficulty it would have been sufficient, and at the same time simpler, to have caused the edge, *a*, and the piece, *h*, upon which it rested to have changed places.

There was yet another disturbing element, the small piece, *b*, resting on top of the rail, was like a wedge gradually forced into it, especially in the softer metals; and thus perhaps materially affecting their rupture.

Again the rail was also pressed somewhat into its supports, though in a far less degree, yet sufficiently so to require a deduction in the deflection observed; this was very effectually got over by the interposition of thin steel plates, $\frac{1}{4}''$ thick. The weight of the lever and frame was about $6\frac{1}{2}$ lbs.: the additions to the weight were made at the commencement by augmentations of 1 cwt. each (50 kilogrammes) at a time, then of 5 cwts. (250 kilogrammes), and, when signs of breaking appeared, again of 1 cwt.: there being a first stage during which equilibrium is rapidly attained, so it is no loss of time to proceed by small degrees; next comes a period during which, as it is more slowly reached, experience shows it advisable to increase the progressive loads: and, as symptoms of rupture begin to be manifest, these ought again to be diminished.

This apparatus, the details of which were all carefully studied, might serve as a model in case of a series of experiments made upon building materials: the dish and weights might however be replaced by a graduated water chest.

20. 1°. *Resistance to vertical pressure.*

The single **T** rail has in itself, like all non-symmetrical bodies yielding laterally, a method simple, and often made use of, to regulate the principle of its form, viz., by comparing the weight necessary to break it in an upright, with that required in an inverted position. If these are equal, then the section is faulty; for this proves equality between the primary opposing strains (tension and compression), and tends to symmetry of form: if however they differ, then the non-symmetrical form is, by this fact, established in principle; only it must not be carried too far, and particularly not be applied in the wrong direction.

Mr. Weishaupt's experience proves, and it is in accordance with those made before him, that for single-headed rails, the resistance to breakage is notably greater in an upright position (with the head above), than in an inverted one: take for example the rail of the Westphalian line, where the difference is very marked between the upper and the lower members; this was ruptured in the upright position, under a weight of 16 tons 2 cwt., and 5″·61 of deflection: inverted, it required 19 tons 15 cwt., and deflected 5″·92.

Thus, granting an inequality in size between the upper and lower members, (and this there ought to be, as this experiment proves the inequality of the primary opposing strains), it is not in the former, but in the latter that the excess of metal ought to exist. Doubtless there are causes of destruction, to which the top member is especially exposed, which preclude this disposition of metal; nevertheless it is important here to note that, if the larger diameter of

the head is at all justified, it is certainly not on the score of resistance to lateral strain.

It is well known moreover, that, when rails break in actual use, whether they be single T, or double-headed, it is almost always the lower member that gives way; and hence may be asserted, for both these types, a weakness in resistance to tension.

Let us here remark that this fact also proves, that a length of rail, when weighted, cannot be considered as rigidly fixed upon its supports; for were it so, as the direction of the longitudinal strains alter at each point of flexure, partial rupture ought to take place as often in the upper, as in the lower member.

Experiments of this kind made upon another kind of non-symmetrical rail, the inverted T, have given a different result, but one that may easily be explained: though some of the rails experimented upon have a little more metal in the head, than in the foot, and vice versâ, yet it is always in an upright position that the resistance has been greatest.

The influence of the amount of metal is thus counterbalanced by another, its form; for in reality the foot, thus thinned out, offers a good resistance to tensile strains; but very poor to compressive; it is therefore evident, as long as the areas of both top and bottom members are nearly equal, which is always the case in this form of rail, that the greatest resistance always shows itself, no matter which way the difference of metal be, in that position in which the flattened portion of the section is in tension.

The following series of experiments deserves reproduction, since it shows, once the equality between the two members is disturbed, how rapidly this resistance diminishes, in proportion as the member in tension is reduced in size. Instead of comparing together rails of different types, which would have differed also in the nature of their metal, rails of but one class, those of the Eastern of Prussia Railway, were experimented upon; diminishing the size of the foot in different degrees, and then comparing them together (Plate III, fig. 10). Each rail was divided into three portions, and loaded up to the breaking point; one in its primitive form; the other two with the foot curtailed, so as to bring them to, somewhat resemble the single T in form.

The following were the various dimensions of the rail.

		Inches.
Height		$4\frac{1}{2}$
Breadth of	foot (original)	4
	head	$2\frac{1}{4}$
	web	$\frac{5}{8}$

TABLE N° 1.

WHERE MADE.	WEIGHT per yard run.	LOAD corresponding to first appearance of permanent set.	LOAD corresponding at breaking.	DEFLECTION corresponding to first appearance of permanent set.	DEFLECTION corresponding at breaking.	RATIO between loads at first appearance of permanent set, and at breaking.	RATIO between deflection at first appearance of permanent set, and at breaking.	QUALITY OF THE BROKEN SECTION.	REMARKS.
	lbs.	tons. cwt.	tons. cwt.	inches.	inches.				
1. Laura (Silesia)........	$65\,^3/_4$	9· 1	$30·\ 6^1/_4$	0·071	3·179	1 to 3·34	1 to 44·9	Coarse grained, finer towards the edges.	
	56	$6·16^3/_4$	$23·\ 8^1/_2$	0·071	2·511	1 to 3·34	1 to 35·6		
	$55\,^1/_4$	6· 8	$22·15^3/_4$	0·079	2·255	1 to 3·35	1 to 28·7		
2. Piedbœuf, Röthe-Erde....	$66\,^1/_2$	6· 8	»	0·055	»	»	»	....	(a)
	56	$5·\ 1^1/_4$	»	0·055	»	»	»		
	$55\,^1/_2$	$4·12^1/_2$	18· 7	0·043	»	1 to 3·95	»	Fibrous.	
3. Piepenstock and Co., Hörde.	$66\,^1/_2$	$8·\ 3^1/_4$	»	0·067	»	»	»	....	(b)
	56	$8·\ 3^1/_4$	»	0·067	»	»	»		
	56	6· 8	»	0·063	»	»	»		
4. Eberhard and Hösch, Düren.	66	$11·\ 5^1/_2$	»	0·090	»	»	»	....	(c)
	56	$6·16^3/_4$	»	0·063	»	»	»		
	$55\,^1/_2$	5·19	$19·\ 4^3/_4$	0·055	3·383	1 to 3·23	1 to 61·5	Portion of foot fibrous, rest fine grained.	
5. Haniel and Huyssen, Sterkerade..........	$65\,^1/_2$	$8·\ 3^1/_4$	28· 2	0·063	5·427	1 to 3·43	1 to 86·3	Foot fibrous, rest fine granulated.	
	$55\,^1/_2$	5·19	$20·11^1/_2$	0·055	6·665	1 to 3·45	1 to 121·1	Fibrous in foot and top of section, coarser grain.	
	$55\,^1/_2$	$7·\ 5^3/_4$	$20·\ 2^1/_2$	0·067	7·195	1 to 2·78	1 to 105·9	Fibrous almost throughout.........	(d)

(a) With a load of $26^{tons}.6\frac{1}{2}^{cwt}$, it deflected 5''·512 without breaking.
(b) With a load of $24^{tons}.2\frac{1}{4}^{cwt}$, it deflected 2''·913 without breaking.
(c) Bore a weight of $28^{tons}.1^{cwt}$ without rupture.
(d) Under the latter loads, the outside layers became detached as the welding gave way.

CONTINUATION OF TABLE № 1.

WHERE MADE.	WEIGHT per yard run.	LOAD corresponding to first appearance of permanent set.	LOAD corresponding at breaking.	DEFLECTION corresponding to first appearance of permanent set.	DEFLECTION corresponding at breaking.	RATIO between loads at first appearance of permanent set, and at breaking.	RATIO between deflection at first appearance of permanent set, and at breaking.	QUALITY OF THE BROKEN SECTION.	REMARKS.
	lbs.	tons. cwt.	tons. cwt.	inches.	inches.				
6. Michiels and Co., Eschweileraue.	65 3/4	8·12 4/4	27· 4 1/4	0·063	4·051	1 to 3·15	1 to 64·4	Fibrous, except in some granulated portions in the centre of the head and of the web.	
	56 1/2	7· 5 3/4	21· 0 1/4	0·067	5·230	1 to 2·88	1 to 78·3		
	55 1/2	6·16 3/4	19·13 3/4	0·063	5·847	1 to 2·88	1 to 80·5		
7. Königshütte (Silesia).	65 1/2	9· 1	27·13 1/4	0·071	3·592	1 to 3·05	1 to 50·7	Coarse grain inside, finer towards edges, somewhat fibrous in the foot.	
	56 1/2	7· 5 3/4	21· 9 1/4	0·067	4·409	1 to 2·94	1 to 65·8		
	55 3/4	5·10 1/4	21· 0 1/4	0·055	4·511	1 to 3·81	1 to 82·0		
8. Michiels and Co., Eschweileraue.	66	8·12 1/4	28·11	0·067	4·307	1 to 3·30	1 to 64·4	Fibrous, except in part of the head.	
	53 1/2	5· 1 1/4	18·16	0·059	4·307	1 to 3·71	1 to 73·9	Fibrous, almost throughout.	
	49 3/4	4· 3 3/4	15· 5	0·055	2·511	1 to 3·64	1 to 45·2	Fibrous at top, granulated web.	
9. Königshütte.	67 1/4	9·10	30· 6 1/4	0·079	5·435	1 to 3·19	1 to 69·1	Fine steel-grained, fibrous in a portion of foot.	
	53 3/4	5·10 1/4	20· 2 1/2	0·059	4·358	1 to 3·64	1 to 73·9	Fine grained, fibrous in lower part of web.	
	49 3/4	3·14 3/4	16· 2 3/4	0·055	3·796	1 to 4·31	1 to 69·0	Fine grained, fibrous on one side of web.	(e)
10. Laura.	65 1/2	8· 3 1/4	30· 6 1/4	0·067	3·434	1 to 3·71	1 to 51·4	Fine grain, very fine at edges of foot.	
	62 3/4	7·14 1/2	27·13 1/4	0·063	4·051	1 to 3·57	1 to 64·4	Fine grain, very fine in web.	
	59	6·16 3/4	23·13 1/2	0·063	1·949	1 to 3·46	1 to 31·0		
11. Pledbœuf, Röthe-Erde.	67 1/2	6·16 3/4	26· 6 3/4	0·055	»	1 to 3·84	»	Fibrous, fractured portion slightly crystallized in centre of head.	
	64 1/4	6· 8	25· 8 3/4	0·055	3·878	1 to 3·97	1 to 70·5		
	60 1/2	5·10 1/4	23· 4	0·047	3·690	1 to 4·21	1 to 78·2		

(e) The lower member was almost entirely cut away.

During the whole of these experiments, made upon rails differing very much in quality of metal, in no case did the head give way the first, even where the foot had been left untouched; it was always the tearing asunder of this portion, that preceeded total rupture.

The following table shows the comparative influence, which the greater, or lesser diminution of the foot has upon the resistance of the rail.

TABLE No 2.

WHERE FROM.	AREAS. (The area of the non-mutilated rail is taken as unity.)	LOADS PRODUCING a sensible permanent deflection. (The loads of the non-mutilated rail are taken as unity.)	LOADS PRODUCING breakage.
1. Laura	1·000 0·850 0·840	1·000 0·775 0·706	1·000 0·770 0·750
2. Röthe-Erde	1·000 0·846 0·837	1·000 0·792 0·723	» » »
3. Horde	1·000 0·971 0·844	1·000 1·000 0·783	» » »
4. Düren	1·000 0·851 0·843	1·000 0·607 0·528	» » »
5. Sterkerade	1·000 0·848 0·846	1·000 0·891 0·729	1·000 0·716 0·732
6. Eschweileraue	1·000 0·860 0·844	1·000 0·846 0·794	1·000 0·772 0·723
7. Königshütte	1·000 0·860 0·849	1·000 0·804 0·609	1·000 0·775 0·760
8. Eschweileraue	1·000 0·811 0·756	1·000 0·585 0·485	1·000 0·660 0·534
9. Königshütte	1·000 0·809 0·752	1·000 0·589 0·393	1·000 0·663 0·532
10. Laura	1·000 0·957 0·899	1·000 0·945 0·844	1·000 0·912 0·780
11. Röthe-Erde	1·000 0·967 0·911	1·000 0·928 0·805	1·000 0·964 0·882

Resistance to rupture, as is shown by this table, decreases much more rapidly, than either the area, or the load; a result which proves directly the superiority of the broad-footed rail (where the areas of the head and of the foot are nearly equal), over the single **T** rail.

If this latter form had been more favourable to resistance, as many suppose it to be; or in other words, had there been, with equal areas in the head and foot, excess of metal in this last, then the removal of this excess ought not to have affected its resistance in any sensible way; the above table however proves, that but a slight diminution of the foot diminishes its resistance considerably.

The comparison of a rail, which was made smaller by hand, as the above quoted were, with a single headed one, which has been turned out of the foundry in this form, may be objected to, it is true; and moreover the inferiority of the latter may have been somewhat exaggerated, on account of the greater resistance possessed by those parts, which have undergone the action of the rolls : if however the above manner of experimenting leaves behind it any source of error, it is at least one of but little importance, and one tending constantly in a known direction.

Taking resistance to transverse strain only into consideration, it may be asserted, that there ought to be as much metal in the foot, as in the head of the rail.

The power of wrought iron to resist tensile, as well as compressive strains, in nearly an equal degree, has been for a long time admitted; but, since Professor Hodgkinson's experiments, which tended to assign a lesser value to the latter, this equality has been disputed; it may however still hold good for iron in bars, and yet not so for other solid figures, such as wrought iron tubes, which, from their form, are unfavourable to those parts, which are in compression; and from their disposition to bend separately instead of yielding by being crushed.

Thus uniformity in the distribution of the metal, though not suited for certain wrought iron girders, exception being made of those joints, which are in tension, may yet be perfectly fitted for rails.

21. Let us now consider the influence, which the form of the lower member has upon this equality of section, it being always the transverse resistance of the rail in an upright position, which is treated of.

The Vignoles rail may be looked upon as a variation of the double-headed; the lower head being simply flattened out. By diminishing the height, its transverse resistance is likewise decreased: which may however be counter-

acted, either wholly, or in part, by introducing a more favourable ratio between the general form of the rail, and the area of the foot; and consequently by an increase of its mean resistance by unit of section.

This comparison could not be made, as in the experiments above quoted, under conditions of absolute identity of iron; the rails compared together differed both in quality and in form : however the experiments were sufficiently numerous to separate any influence, if it really exist, of differenco of form, from that of species of metal.

The following rails were experimented upon.

Inverted T.	*Double-headed.*
Eastern of Prussia	Westphalian
Stargard to Posen	Berlin—Anhalt (of English make)
Berlin to Hamburg	Berlin, Potsdam, and Magdeburg
Thuringia	
Lower Silesia	

Each of these types according to Mr Weishaupt has an advantage, the first offers a somewhat longer resistance to rupture; the second endures longer without receiving any permanent set; these remarks cannot however be laid down as axioms; for, from a series of improvements such as these, special properties of this nature are less to be inferred, than is their practical worth, which may sometimes be hidden beneath the chances of an experiment; and the fact, that very nearly analogous differences occurred between rails of the same type, and of almost identical section, proves this.

	Tons. Cwt.
In the "Berlin and Anhalt" double-headed rail, rupture took place under a load of.	17·17½
In the "Westphalian," double-headed, under.	15·13¼
Whilst the first permanent set of the former was under	4·12½
And of the latter, under.	5·19

It is impossible to attribute, to influence of form, differences, which affect in an equal degree rails of the same type.

On the score of transverse resistance, both types of rail must therefore be considered to have an equal advantage; preference, for either of these forms of rail, must be sought for under some other conditions.

22. *Permanent set.*

In Germany a slight permanent deflection has often been noticed in rails, which, when new, were perfectly straight. Any permanent alteration of form even though slight, was often regarded as indicative of internal disorganisa-

tion; which, increasing beneath the repeated efforts, that originally caused it, must sooner or later end in rupture.

It has long been known, that this is not necessarily the case with wrought iron, where a slight permanent set may take place without danger: in rails the metal appears to be under the same condition, and that in one case, as well as in the other, the load commences to be in excess only, when elasticity, taken in its rigorous meaning, is disturbed, *i.e.* when the deflection increases at a more rapid rate, than do the loads.

The introduction of a fresh state of equilibrium, indicated by the permanent set, in no way implies, within certain bounds, an alteration of elasticity; so that the effects produced successively by an increasing load may be divided into four distinct periods:

1st. No set remains after the load is removed, which is at all to be measured by ordinary methods.

2nd. Permanent deflection appears; the rail is altered in form; but not so its elasticity; *i. e.* the ratio between the progress of the deflections, and of the loads is still the same.

3rd. Elasticity is disturbed; the deflections are no longer in proportion to the loads, and gradually increase with greater rapidity.

4th. Rupture takes place.

When again submitting those rails, which had already received a slight set, to the same series of loads, Mr Weishaupt ascertained, that they repassed through exactly the same stages; though in subsequent trials under the same loads, the deflections were not as great, as on the first occasion, since there needed to be added to them all, the original deflection of the metal, when in its primitive condition: so that rigorously speaking, ***the application of a load capable of modifying the molecular condition of any body renders it, within certain bounds, more rigid than it was before.***

Although the point, at which permanent set becomes appreciable, and that at which alteration in elasticity commences, are in reality distinct; yet in the metal they are so close, as to be confounded in practise.

In accordance with the experiments of Mr Weishaupt, and of the much earlier ones of Mr Wertheim, the former effect might take place in rails, under lesser loads than they usually have to bear, and therefore a slight alteration in form may generally be regarded as inevitable: it does not however deserve notice, as it neither necessarily indicates a predisposition to rupture; nor does it in any way increase the total deflection under the load; neither has it any appreciable influence on the centrifugal force of the loads in motion.

The following table shows the difference between the two points.

DEFLECTION UNDER LOAD corresponding to		QUALITY OF METAL.
1st appearance of permanent set.	at rupture.	
inches.	inches.	
0·071	3·179	Coarse grained.
0·063	5·427	Fibrous, and finely granulated.
0·063	4·051	Fibrous.
0·071	3·580	Coarse grained, finer at edges.
0·066	4·207	Fibrous.
0·078	5·423	Fine steel-grained.
0·066	3·423	Finely grained.

Two sufficiently remarkable facts have been deduced from the observations of the deflection of those rails, which were left entire : 1° The deflection under a load, which corresponds to permanent set of the longitudinal section of the rail, varies but little, despite the difference in quality of iron; 2° The deflection at rupture differs much, but without there being the slightest connexion between these differences, and that of the prevailing texture of the metal.

To the coefficient of elasticity, this same property has long been known to belong; it is not a constant one, but its variations are nearly independent of the other mechanical, and physical properties of the iron.

I will here mention, but these two conclusions, drawn from a number of observations, too unimportant to consider them further.

23. *Influence of temperature.*

It is well known, that broken rails, as well as axles, and tires occur more frequently in winter, than in summer: many persons attribute this to cold, which renders the metal more inclined to break.

As it is proved by well known experiments, that the resistance of iron increases in moderate climates with the temperature for a few degrees above its mean — 50° in general —, it is also to be presumed, that this resistance diminishes in a similar manner, when the temperature falls belows this point; the increase however appears too gradual, to allow of the decrease having any sensible influence, unless there is some sudden jump in its course, which is but little probable; permitting it to show itself by increased fractures.

Up to the present time the idea, that the resistance of iron was seriously affected by changes of so small an extent in the temperature rested mainly

upon the fact of an increased number of breakages; for rails however this proves nothing, as one circumstance will suffice to explain, at least till proof be given to the contrary; it is but natural that rails should be more easily broken, when the ground, hardened by frost is less compressible, and augments the force of all concussions : it is not of a necessity the internal constitution of the metal, which has been altered; but the external condition of the supports, which has been modified.

I have often remarked a fact, which bears out this opinion, viz., that it is not during very intense cold that breakages are most frequent, but when the weather moderately cold has been of some duration : again these often happen when a thaw sets in after a severe and prolonged frost : this may likewise be explained, for during the frost maintenance is somewhat neglected; a thaw sets in, the various parts hitherto firmly bound together by frost, are set at liberty, and any sleepers, which are badly packed settle down unevenly; in fact the permanent way becomes bad, and the rails are placed in quite as unfavourable conditions, if not more so, than they experienced from hardness arising from the frost (*).

If the observations made upon rails, which have been broken in actual use do not appear such, as to decide the question affirmatively, the results of some special experiments recently made on this point cannot be overlooked.

In France two railway companies, the Paris and Mediterranean, and the Southern, looked upon them as sufficiently conclusive to induce them to decide; that when rails were tested, the height of the fall should vary with the temperature at the time; thereby modifying their original requirements on this point.

It is a matter of so much importance; that the facts, which have appeared to solve this much controverted question, ought to be brought before the reader.

(*) In January 1861, on the short line from Thann to Mulhousen, 132 rails were found to have been recently broken : it was however acknowledged that these rails, of only 50 lbs. to the yard, and on sleepers 2'·7" apart, were too light for locomotives of 31 tons weight, so that it needed but little to attain, or even exceed their limit of resistance; this little was caused by a slight flattening of one of the engine-wheel tires, which on its last journey had caused the breakages.

It was considered advisable to test the rails by means of a falling weight; the monkey weighed 11¼ cwt.; the supports were 2'·7" apart; during the first series of experiments, with the thermometer at 41°, rupture took place under a fall of 12" : in the second series, however, with the temperature at from 43° to 54°, the fall was increased to 1'·8" and even to 2'·4".

Still this does not prove the influence of temperature upon iron, for the temporary apparatus used was simply placed upon the ground, and thereby rendered more sensitive to the variations of its elasticity.

According to the requirements of the Paris and Mediterranean line, each half of a rail, broken in two under a stationary load, and placed on two supports 3'·6" apart, is required to stand without rupture the blow of a monkey, weighing 4 cwt., and falling a height of 4'·11" : the supports, of cast iron, are to rest upon an anvil, likewise of cast iron, weighing at least 9 tons $16\frac{3}{4}$-cwt., and fixed into a block of solid masonry, 3'·3" thick, and measuring 10·0 *s.f.* at its base.

Some of the foundries, supplying the extensive line, fulfilled with ease the required conditions, while others did not do so; breakage taking place under a fall considerably less, than the one required.

The engineers in charge of the permanent way made an analysis of a great number of trials, taken at those foundries the rails from which did not comply with the prescribed conditions : 1st During the winter three months, and 2ndly during the summer three months; they extended over several years, and it was found on an average, that during the latter period the height of fall, required to produce rupture, exceeded that during the former, by about 15".

It was therefore mutually agreed upon by the railway company, and the different foundries, in place of the fixed height 4'·11", to substitute a lower one for low temperatures, and also a greater one for warmer periods : the following were the heights decided upon.

Below 32°.	4'· 3"
Between 32° and 68°.	4'·11"
Above 68°.	5'· 7"

Though these facts cannot be questioned, yet an objection may at first sight present itself against the consequences drawn from them. It may be easily understood, all other circumstances being the same, that rails made during winter may be more brittle, than those manufactured during the summer months; for, on emerging from the rolls, they lie on the foundry floor exposed to the wind on all sides, and are therefore in winter cooled more rapidly, and so receive a species of tempering.

As in general they are tested, and delivered shortly after their manufacture, may not this greater tendency to rupture, as is proved by experience, of rails made and tested in winter, arise rather from the low temperature, which existed during the time of their manufacture; than from its being so at the moment of their being tested? This distinction is certainly not a matter of indifference; for it might perhaps indicate, that it is erroneous to suppose the resistance of the rail varies with the temperature; that the fault lies in the low degree of

the same, to which it was exposed during the process of its manufacture; and, if so, to a defect, which can very easily be remedied.

24. The special experiments, however, which were made at La Villette by Mr Ledru, engineer in chief of the Eastern of France railway; and also at Creusot by Mr Couard, late pupil of the Polytechnic, and of the school of mines, prove the actual existence of the influence, which the degree of temperature, existing at the moment of test, has upon the rail; and which acts directly upon the organization of the iron itself; for the nature of the supports, solid masses of masonry, or better still large blocks of cast iron, precludes all possibility of any disturbing element, arising from the condition of the ground, whether hardened by frost, or not.

Annexed is Mr Ledru's letter upon the subject.

" I have caused to be constructed with great solidity at La Villette a testing apparatus, to enable experiments to be made upon rails of different types, in such a manner, as to bear comparison with one another.

" It was established within the conditions prescribed by most of our railways: the monkey weighs 6 cwt.; the supports are 3'·6" apart, resting, by means of a strong oaken frame, on masonry 4'·0" thick, with a bed of concrete, 1'·8" thick, underneath.

" Each rail tested was cut into two equal parts, one of which was tried in summer, with the temperature in the shade standing at from 78° to 84°; the other was similarly treated in winter with the thermometer ranging from 18° to 23°.

" All the rails came from the same foundry at Styring; and were of the three types, principally in use on the Eastern of France Railway,

Double headed	weighing	75 ¼	lbs per yard.
Single T	—	71 ½	—
Vignoles	—	70	—

" Two series of experiments were made; during the first, commencing at 10", the heights of fall were successively increased 10" at a time; during the second the heights, also beginning at 10", were augmented each time but by 2", and five blows were given at each height.

" Each separate test was repeated upon two different pieces of rail; the results were very similar: the means of each of them are collected in the two following tables, which give the successive deflections observed, the heights causing rupture, and the curve of deflections. " (Plate I, figures 6 and 7.)

FIRST SERIES.

Experiments made under a falling load, the height of fall being increased 10" at a time.

Temperature.	Made during winter.				Temperature.	Made during summer.			
	Form and length of rail.	Where made.	Height of fall.	Permanent set.		Form and length of rail.	Where made.	Height of fall.	Permanent set.
			feet. ins.	inches.				feet. ins.	inches.
21°	P. S. Double-headed. Ten feet.	Styring-Wendel. October, 1863.	» 10	»	79°	P. S. Double-headed. Ten feet.	Styring-Wendel. October, 1862.	» 10	»
			1 8	0·02				1 8	0·03
			2 6	Rupture.				2 6	0·09
								3 3	0·20
								4 1	Rupture.
23°	P. M. Single T. Ten feet.	Styring-Wendel. March, 1862.	» 10	0·01	84°	P. M. Single T. Ten feet.	Styring-Wendel. March, 1863	» 10	0·01
			1 8	0·06				1 8	0·08
			2 6	0·16				2 6	0·20
			3 3	0·33				3 3	0·38
			4 1	Rupture.				4 1	0·63
								4 11	0·93
								5 9	1·29
								6 7	1·74
								7 5	1·98
								8 2	2·46
								9 0	Rupture.
18°	Vignoles. Ten feet.	Styring-Wendel. February, 1861.	» 10	»	79°	Vignoles. Ten feet.	Styring-Wendel. February, 1863.	» 10	»
			1 8	0·02				1 8	0·04
			2 6	0·09				2 6	0·14
			3 3	0·22				3 3	0·28
			4 1	0·40				4 1	0·48
			4 11	0·66				4 11	0·73
			5 9	Rupture.				5 9	1·03
								6 7	1·38
								7 5	1·79
								8 2	Rupture.

P. S. rail of the Paris and Strasbourg Railway. — P. M. rail of the Paris and Mulhousen Railway.

SECOND SERIES.

Experiments made under a falling load; the height of fall being increased 2" at a time, and 5 blows given at each height.

TEMPERATURE.	MADE DURING WINTER. Form and length of rail.	Where made.	Height of fall.	Permanent set (*).	TEMPERATURE.	MADE DURING SUMMER. Form and length of rail.	Where made.	Height of fall.	Permanent set.
			feet. ins.	inches.				feet. ins.	inches.
21°	P. S.	Styring-Wendel.	» 10	»	79°	P. S.	Styring-Wendel.	» 10	0·01
	Double-headed.	October, 1862.	1 0	0·02		Double-headed.	October, 1862.	1 0	0·02
	Ten feet.		1 2	0·02		Ten feet.		1 2	0·03
			1 4	Ruptured at 1st blow.				1 4	0·05
								1 6	Ruptured at 1st blow.
23°	P. M.	Styring-Wendel.	» 10	0·02	84°	P. M.	Styring-Wendel.	» 10	0·02
	Single T.	April, 1863.	1 0	0·04		Single T.	April, 1863.	1 0	0·06
	Ten feet.		1 2	0·07		Ten feet.		1 2	0·11
			1 4	0·11				1 4	0·18
			1 6	0·18				1 6	0·29
			1 8	0·28				1 8	0·43
			1 10	0·40				1 10	0·59
			2 0	0·57				2 0	0.89
			2 2	Ruptured at 1st blow.				2 2	1·18
								2 4	1·50
								2 6	Ruptured at 5th blow.
18°	Vignoles.	Styring-Wendel.	» 10	0·01	79°	Vignoles.	Styring-Wendel.	» 10	0·01
	Ten feet.	February, 1863.	1 0	0·02		Ten feet.	February, 1863.	1 0	0·02
			1 2	0·04				1 2	0·04
			1 4	0·08				1 4	0·08
			1 6	0·12				1 6	0·14
			1 8	0·17				1 8	0·23
			1 10	0·28				1 10	0·34
			2 0	Ruptured at 1st blow.				2 0	0·47
								2 2	0·57
								2 4	0·75
								2 6	Ruptured at 2nd blow.

(*) Deflection noted after every five blows, given at the same height.

" Comparing only the height of fall producing rupture in winter and in summer,
" the following is the result.

	FIRST SERIES.		SECOND SERIES.	
	Winter.	Summer.	Winter.	Summer.
Double-headed.	2'·6"	4'·1"	First blow at. . 1'·4"	First blow at. . 1'·6"
Single T.	4'·1"	9'·0"	First blow at. . 2'·2"	Fifth blow at. . 2'·6"
Vignoles.	5'·9"	8'·2"	First blow at. . 2'·0"	Second blow at. 2'·6"

" This series of tables prove most certainly, that the degree of temperature has a
" great influence upon the resistance of rails to concussion, and, that their greater
" tendency to break in winter, is not due entirely to the hardening of the ground by
" frost.

" Nevertheless it appears to me, that the principal cause of these breakages during
" winter, is owing to the unequal settlement of sleepers, partially embedded in a sub-
" stance, which is hardened into a cake at the surface; thus preventing their being
" packed up.

" For it is generally after a succession of frosts and thaws, that ruptures are most
" numerous; and not during a long continued one.

" Paris, June 12th. 1866. "

25. In the testing apparatus at Creusot the cast iron bearers, likewise 3'·6" apart, were constructed according to the requirements before stated (23) of the Paris and Mediterranean line; and rested upon a cast iron block ten tons in weight; the monkey weighed only 4 cwt.

The results however obtained by the two machines can only be compared, after being thoroughly analysed, by means of numerous experiments made upon rails of the same type. The 4 cwt. monkey at Creusot, on account of the large and almost incompressible foundation common to both bearers, may be considered equal to one of 6 cwt., falling on a bed of concrete and masonry, as at La Villette: though this is of but little import to the question now treated of. The following is the method adopted by Mr Couard.

The rails tested were double-headed, 16'·6" long; each length was broken in half, by means of a stationary weight, and each part was during summer again fractured, by means of a monkey, at a distance of 3'·3" from the broken end: the mean of the heights of fall, causing rupture, gave the resistance in summer.

The other portion, 5'·0" long, remaining from each half rail, was put aside, and broken in a similar manner during the winter: the ratio between the pieces

of rail experimented upon was therefore as 1·67 to 1, instead of their being equal as at La Villette.

This necessarily required a correction, in order to eliminate the influence arising from this inequality, decidedly unfavourable to the shorter length; a series of special experiments were instituted for this purpose, both portions, 8′·3″ and 5′·0″ long being broken at the same temperature, which was always that of the rail itself; to ascertain which, a thermometer on a small metal plate, covered with a woollen cloth, was placed upon it, and read off at the expiration of an hour.

1° *Preliminary trials.*

At first the initial height of fall was 4′·11″; successively augmented 4″ at a time till rupture took place; this was however found to be too great for pieces only 5′·0″ long; for in experiment N° 2 (both pieces), N° 3 (one piece), and N° 10 (both pieces), all were broken at the first blow; and perhaps even a lesser fall might have produced a similar result.

1° *Preliminary experiments made at the same temperature, upon pieces* 8′.3″ *and* 5′.0″ *long respectively, to ascertain the correction due in each.*

N° of experiment.	HEIGHT of fall producing rupture of pieces 5′·0″ long. (commencing at 4′·11″ high).	MEAN heights.	HEIGHT of fall producing rupture of pieces 8′·3″ long. (commencing at 4′·11″ high).	MEAN heights.	RATIO between the mean heights.	REMARKS.
	Feet. Ins.	Feet. Ins.	Feet. Ins.	Feet. Ins.		
1	5·11 5·7	5·9	5·3 5·8	5·3	0·913	The mean of the eleven ratios in the last column is 0·899; or say 0·9.
2	6·3 6·7	6·5	4·11 4·11	4·11	0·766	
3	5·3 5·3	5·3	4·11 5·3	5·1	0·968	
4	5·7 6·7	6·1	5·3 6·7	5·11	0·973	
5	6·3 6·3	6·3	5·7 5·11	5·9	0·920	
6	6·11 5·7	6·3	5·7 5·3	5·5	0·867	
7	7·3 8·10	8·0	5·7 7·3	6·5	0·802	
8	5·11 5·7	5·9	5·3 5·3	5·3	0·914	
9	6·3 5·11	6·1	5·11 5·11	5·11	0·973	
10	6·3 5·7	5·11	4·11 4·11	4·11	0·831	
11	5·11 5·3	5·7	5·3 5·7	5·5	0·970	

Hence if the heights causing rupture in the 8'·3" pieces, which were tested during the summer, be multiplied by 0·9 the product will be equivalent to those, which produced the same result in the 5'·0", lengths experimented upon in winter.

2° *Experiments.*

In the following series, the initial height of fall was in winter reduced to 4'·3", and even to 3'·6", for certain rails, which were considered weak : no doubt a wise precaution, but one that ought to have been extended to all, in summer as well as in winter; for, when these experiments commence at different points, their results can no longer be compared together.

Thus in experiments N°ˢ 10 to 15 (summer series) a lesser fall might probably have caused rupture had they commenced at 3'·6" instead of at 4'·11", as was the case with the six corresponding ones tested in winter : likewise the first piece in N° 7, and the second in N° 8 (winter series) were both broken under a fall of 5'·7"; the latter offering in reality the greater resistance, as it had been more or less weakened by the preceeding blows at 4'·3" and 4'·7" : and to which the other had not been exposed.

In these, as in the preliminary trials, the heights were increased 4" at each time.

2° *Experiments made in winter and in summer. Of the winter experiments the gross results only are given; of the summer ones, the results are in gross; and likewise corrected to a length of 4'·11".*

Nº of experiment.	Made in August 1864.				Made in February 1865.				Difference between the two temperatures.
	Fall producing rupture (commencing at 4'·11").	Mean Fall.	Temperature.	Corrected Height.	Initial Height of fall.	Fall producing rupture.	Mean Fall.	Temperature.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
	Feet. Ins.	Feet. Ins.		Feet. Ins.	Feet. Ins.	Feet. Ins.	Feet. Ins.		
1	13·1 10·10	12·0	97°	10·10	4·11 4·11	5·7 6·3	5·11	21°	76°
2	9·6 10·2	9·10	102°	8·10	4·11 4·11	4·11 5·7	5·3	21°	81°
3	12·2 12·9	12·6	86°	11·3	4·11 4·11	6·3 6·3	6·3	21°	65°
4	11·6 11·6	11·6	90°	10·4	4·11 4·11	5·7 6·3	5·11	21°	69°
5	8·2 8·10	8·6	102°	7·8	4·11 4·11	4·11 4·11	4·11	21°	81°
6	12·9 10·10	11·10	84°	10·8	4·3 4·11	5·7 6·3	5·11	21°	63°
7	8·2 5·7	6·11	93°	6·3	4·11 4·3	5·7 4·3	4·11	21°	72°
8	10·2 10·10	10·6	115°	9·5	4·11 4·3	4·11 5·7	5·3	21°	94°
9	8·10 11·6	10·2	97°	9·2	4·11 4·11	5·7 6·3	5·11	21°	76°
10	10·2 12·2	11·2	97°	10·0	4·11 3·7	5·7 4·11	5·3	19°	78°
11	14·9 13·5	14·1	97°	12·8	4·11 3·7	5·7 4·3	4·11	19°	78°
12	6·11 8·10	7·10	104°	7·1	4·3 3·7	4·3 4·3	4·3	19°	85°
13	8·2 7·7	7·10	100°	7·1	4·3 3·7	4·3 4·3	4·3	19°	81°
14	8·10 8·10	8·10	95°	8·0	4·3 4·3	4·11 4·11	4·11	19°	76°
15	9·6 11·6	10·6	95°	9·5	3·7 3·7	4·11 4·3	4·7	19°	76°

The experiments, Nos 2, 5, 7, 8, 12 and 13, ought strictly to be set aside, for in all of them, either one, or both pieces, broke under the first blow, with a 4'·11" fall, and therefore perhaps might have yielded with a lesser one.

These experiments, as well as those at La Villette, show the very marked influence, which very slight variations in temperature, have upon the resistance of iron to concussion.

26. To these results may be added the following information, kindly afforded by Mr Lan, a mining engineer, and a director of the Commentry and Châtillon Iron Foundry Company.

" About ten or twelve tons of double-headed rails, for the Paris and Mediterranean " railway, were some months ago rejected, as wanting in resistance to the concussive " test; notice was again given some few days ago (June 1866) to the inspector, and " these rails, which previously had yielded under 4'·9" and 4'·11", at a temperature of " from 50° to 54°, now remained good under a 5'·4" fall, with from 84° to 86°.

" Several times previously had analogous facts taken place, but I had never had an " opportunity of examining them till the present occasion, which has completely con-" vinced me of the influence exercised by the temperature upon resistance to con-" cussion.

" The difference of temperature above mentioned is considerable, but if I may be-" lieve our principal manufacturers, it is when the thermometer ranges between 50° " and 32°, or even lower still, that this resistance diminishes most rapidly. "

There is no doubt whatever, that the influence of a slight variation of temperature upon armour plates is similar to that just mentioned by Mr Lan : for the specifications of the French navy expressly state, that, should the temperature be at, or below 32°, the plates shall be heated, before being fired at.

27. We cannot therefore any longer deny the existence of this action; it would however be interesting to know, whether it acts equally upon rails from all foundries; and also, if in some cases it is not so very weak, as to be almost null.

Likewise, to ascertain what element in the constitution of the iron, these variations of temperature act upon. Whether it is the resistance of the metal to rupture by tension, or by compression? or the coefficient of elasticity, and consequently the deflection beneath the blow? or whether it be both of these?

In both series of experiments at La Villette, the deflections observed were always, under the same heights, greater in summer, than in winter; and, it was only for the Vignoles rail, in the second series of experiments, that the differences were small; and, at the commencement, even had an opposite tendency.

The metal would therefore seem to become tougher, as the temperature falls: however the permanent set only was noted, though the other deflections would probably have followed in an analogous series; and the knowledge of them would have been more conclusive for this purpose.

In order to solve this question, some data are wanting about stationary breaking loads and their deflections, taken at extreme temperatures: and it is very desirable, that such should be made.

To Mr Chaperon, engineer in chief of the Paris and Mediterranean line, I am indebted for the following observations of the deflections of a Vignoles rail 19'·8" long, and placed on two supports 3'·6" apart.

	DEFLECTION CAUSED BY			
	13tons. 5 3/4 cwt.		19tons. 13 3/4 cwt.	
	inch.	Mean.	inch.	Mean.
July 1865 (mean)	0·09	0·09	0·14	0·14
August 1865 (mean)	0·09		0·13	
September 1865 (mean)	0·09		0·15	
December 1865 (mean)	0·08	0·08	0·14	0·13
January 1866 (mean)	0·07		0·13	
February 1866 (mean)	0·08		0·12	
March 1866 (mean)	0·08		0·14	

According to the result of these experiments, the rigidity of the metal would hardly be affected by changes in temperature; their action would tend principally towards correlative variations in the cohesion itself.

The experiments, made some time ago at the Franklin Institution, have already established this correlation (*); they were however taken at such extremes of temperature, some at 160° and others at 32°, that they hardly afford any clear conclusion upon the question now treated of, and which therefore needs special experiments on this head.

Happily this sensitiveness, in resistance of rails to changes in temperature, is of but little importance: nothing proves this better than the uncertainty which has up to the present time existed as to its reality, and also the complete absence of precaution, which prevails upon the subject.

Even the frequency of breakages in countries like Russia, where the rails are exposed to much lower temperatures, than in these moderate climates, did not attract public attention to it.

28. 2ndly. ***Resistance to horizontal strain.***

This is of but secondary importance; for a rail, which fulfils the other conditions, may by this very fact be considered to comply with this also, provided it be properly fastened on its supports.

It is interesting to consider this matter in connection with the Vignoles rail; even if it be, but to leave no room for objections to it.

In these experiments the rail was simply laid down on the ground; the lever merely pressing against the side of the head, as do the flanges of the wheels;

(*) An account of these experiments was published by Mr Combes, in his " Treatise on the working of mines ". Vol. I, page 483, etc.

the arrangement of the bearers was however a little more favourable, than it is in practice, especially with the Vignoles rail, which is deprived of any lateral support the chairs might afford.

The principal consequence, and to a certain point an unlooked for one, of these experiments is the constant uniformity of deflection maintained throughout the whole area of each individual cross section, despite the extreme position of the point of application of the load; or in other words the cross section, though more or less distorted, never lost its symmetry of form relatively to its original axis.

A rail of the Lower Silesian railway (Plate II, fig. 20), with a web $\frac{5}{8}''$ thick, under a load of 4 tons 14 $\frac{1}{2}$ cwt., showed no disposition, on the part of the foot, at any time to hang back, more than the head did.

The resistance of the head and of the foot, very tenacious beneath the influence of vertical strains, is therefore so likewise under very considerable horizontal ones: a fact which at once establishes the superiority of the inverted ⊤ rail, over the single and the double headed ones, as far as resistance is concerned, supposing also the disposition of their bearers to be the same; for the flattening out of the foot only increases the momentum of inertia, relatively to the vertical axis.

The double-headed rail of the Westphalian line, having an area of section nearly identical with the inverted ⊤ of the Berlin and Potsdam, under the same load, 2 tons. 16 cwt., gave a greater deflection in the ratio of 1.7 to 1, than the latter did.

The difference of area between this same rail of the Westphalian line, and that of the Eastern of Prussia is as 1 to 1.13, yet their rigidity is as 1 to 3.15.

In the latter rail permanent set commenced under a load of 2 tons. 17 $\frac{1}{2}$ cwt., or only one third of that, which produced the same effect, when acting in the direction of the height of the rail.

The following table will indicate the amount of deflection, whilst under load, and also of permanent set afterwards remaining, due to the various weights above this point.

LOAD.	DEFLECTION	
	whilst under load.	permanent.
tons. cwt.	inch.	inch.
2·17 1/2	0·10	0·002
3· 6	0·11	0·004
3·14 3/4	0·13	0·008
4· 3 3/4	0·15	0·024
4·12 1/2	0·18	0·027
5· 3 1/4	0·22	"
5·10 1/4	0·32	0·032

It is very remarkable, that the symmetry of the cross section should be maintained, and the whole section thus deflect together, under loads so considerable, and applied in a manner so unfavourable to it.

These facts ought to be taken into consideration, in determining the thickness of the web; and, provided the quality of the metal be not too soft, it may be considerably reduced, without detriment to the rigidity of either head, or foot, even where the pressure is applied under most disadvantageous conditions.

29. The Vignoles, or inverted ⊤ rail possesses therefore, as far as resistance is concerned, an incontestable superiority over the single ⊤ rail; and, on the same point, has at least an equal advantage with the double-headed.

Resistance however is but one part of the question, let us therefore consider the rest.

At the commencement, it is best to cite the arguments, which are brought forward in favour of each of the three types.

1° The double-headed rail has a characteristic property of its own; it may be reversed, so as to bring the lower face uppermost; and thus possesses two rolling surfaces instead of one.

2° The single ⊤ rail, while sacrificing a portion of its transverse resistance, strengthens the part, which is exposed to the immediate action of the wheels; and which alone, when the rail is strong enough, undergoes any alteration: besides this type of rail requires a considerably smaller chair.

3° The principal argument in favour of the Vignoles rail is the total absence of any chair.

Is this advantage too dearly purchased at the cost of sacrificing the power of turning the rail?

For this is the main question, into which the comparison between the in-

verted ⊤ rail, and the double-headed one resolves itself; though the former, it is true, has no lateral support from its bearers, yet the experiments already quoted (28), and better still the lengthened experience of the German Railways, prove that this form of rail has no tendency to overturn by the action of horizontal pressure, and that, when firmly fastened down by the foot, no support is needed higher up.

On one side therefore, there rests the advantage of turning the rail over; on the other that of doing away with chairs.

30. *Returning of the double-headed rail.*

To turn a rail over, so as to bring its lower head uppermost, is a practice condemned by many engineers; in as much as the head, which is so worn, as no longer to present a fair rolling face, cannot be made to fit tightly in a chair, and hence the rail becomes unsteady: moreover as the rail has been for some time exposed to strains in one direction, and the metal as it were become accustomed to them in that direction, it is somewhat dangerous to alter it, especially is it so, to expose iron, which has become crystallized, more particularly in that head, hitherto uppermost, to tensile strain; and which it is therefore, but little fitted to resist.

In one word, to turn a rail is, if we may believe its opponents, a practice now completely condemned.

This however is not the case, for the custom is still as much in force now, as it was twenty years ago, on all lines using double-headed rails.

The practice in itself may not be bad, but its worth is sometimes overestimated, and often abused.

Perhaps a rail, already worn and considerably weakened on its upper face, is turned, in order to get a little more wear out of it; the result is a series of ups and downs on its surface, looseness in the chairs, all manner of inconveniences of this kind, and perhaps even breakage.

Sometimes a reaction sets in, and the practice itself is proscribed; instead of seeking to regulate its use, within certain bounds.

Take for example the Wiesbaden and Frankfort Railway (Taunus line); a large number of rails, which had been much worn during fifteen years constant use, were laid down again, after having been turned, and fish-plates bolted at the joints; thereby hoping to get something more out of them: during the winter of 1853 a quantity of rails were broken, and on inquiry it was found, that all the fractured ones were rails, that had been turned.

For the present, the question of change in the molecular condition of the metal may be waived, as these breakages may easily be explained without it;

for these rails, independently of a considerable alteration in the form of the upper head, bore on their lower faces the marks of the position of the chairs strongly indented in them; and, though the wearing action of the wheels may gradually efface these marks, if they be slight, yet in this case they entailed a series of concussions, resulting eventually in the breakage of the rail. When used judiciously, the practice of turning rails cannot be found fault with; but in no case should this be done where, either the upper face is much worn, or the lower one is indented at the spots, where the chairs have been; the cause of these marks will be treated of further on (39).

Mr Bernard, a late pupil of the School of mines, and engineer on the Northern of France (Belgian section), in the following letter mentions the result of his observations on this subject.

" When a rail is still in a condition to be turned, the duration of the second face " may be sometimes reckoned, as about one quarter less than that of the first one.

" Considering, however, that many rails, for instance the 63lbs ones of the Namur and " Liege line, are so flattened, as no longer to fit properly into the chairs, and that " others cannot be keyed up tightly, owing to one side being completely worn away, " the duration of wear of the second face can, scarcely ever, be put down at more than " half that of the first used. "

In a letter published in 1859 (*) by Mr Delerue, engineer in chief of the Paris and Mediterranean Railway, the importance of turning rails was clearly shown by certain figures; for at this time more than 17 °/₀ of the rails, in use on the section from Paris to Lyons, had been turned.

This property of the double-headed rail is no doubt a very useful one, and justly prized as such; but still it is not such, as to counterbalance the advantage of doing away with chairs altogether.

It is a cause of no small surprise, that in some cases persons, though sufficiently convinced of the objections of turning rails, to induce them to discard the double-headed one, yet have, through right or wrong, adopted the single T, thereby still requiring the aid of chairs; as for instance on the " Wiesbaden and Frankfort ", the " Lyons and Mediterranean ", the " Mulhousen ", the " Rhone and Loire ", on some of the Belgian, and on the Lombardy lines of railway.

31. The reasons, which induced the " Lombardy and Central of Italy "

(*) A letter on the question of " What kind of permanent way ought to be adopted, on any extensions of the line ".

Railway C° to adopt this form of rail, are collected in the following long extract from a letter of Mr Montegazzo, engineer of those lines.

"The only important reason adduced, for preferring the Vignoles rail to our own, is "that the former dispenses altogether with chairs, and is somewhat more economi- "cal in its first cost; but still requires the same size of head, the same breadth of "web, and a like height, as the chair-rail does.

"Now-a-days, as railways are made, with sharp curves and steep gradients, the "tendency is to increase the weight of locomotives, and the distance between the axles "of the wheels; there is in all these a source of considerable wear to the upper "member, more especially on its side; it is therefore absolutely necessary, that it "should present, even after some months wear, a rolling surface of at least $1\frac{1}{2}''$, and "enough of depth at the side to withstand the friction of the flanges of the wheels: "to effect this we consider, that our chair-rail is the minimum possible.

"Now, as all these requirements are the same in the case of the Vignoles rail, it "is impossible to deny, that the breadth of its foot will render it at least 8lbs per yard "heavier, than our single headed one.

"To double-headed rails we have never turned our attention; for a rail, which is "composed of a good quality of metal, and well welded together, will stand wearing "away to a depth of $\frac{3}{4}''$, in which condition it is useless to think of turning it: on "the score of resistance too, equality between the upper and lower members seems "to be unnecessary for rails, weighing more than 73lbs per yard. The slight economy, "which is effected in favour of the Vignoles rail, by the suppression of the chairs, "over the additional 8lbs per yard, is no reason, in our eyes, for adopting this form "of rail, if the following facts be taken into consideration."

"1st In the Vignoles system of permanent way there is, but one spike to resist the "active lateral pressure of the wheel-flanges pressing the rail outwards, whereas in "ours, both spikes act together by means of the chair. This alone seems sufficient "to cause the rejection of the inverted ⊤ rail, especially in curves; though the defect "might certainly be remedied by means of small saddles, or bed plates, weighing "8 or 9lbs apiece, which would however so far diminish the economy, arising from "the suppression of the chairs, as to render it almost null.

"2ndly The fish-plates, which we employ, being much broader than can be used "with an inverted ⊤ rail, are therefore stronger, and more effective.

"3rdly As the single ⊤ rail can be bent much more easily, than the Vignoles one, the "result is, that in very sharp curves, such as crossings, the former produces a per- "fect curve, whereas the latter gives only a series of polygons. Moreover curving "considerably alters the foot of a Vignoles rail, which is about $4\frac{1}{2}''$ in breadth, "against about $2\frac{1}{4}''$ in the other; its lateral fibres are thus stretched about double as "much, as in the single ⊤ rail.

"4thly The substitution of a chair-rail may be performed with much more rapidity "and ease, and without touching the spikes; whereas a Vignoles rail requires them "to be drawn, and the holes in the sleepers to be plugged up.

"5thly As the price of sleepers is always increasing, economy in their dimensions "ought to be observed; with chairs, a sleeper 6" broad on its upper face is sufficient; "but this, with a Vignoles rail, would soon cause it to penetrate into the wood; the

" latter system requiring from 8", to 9" of bearing surface : in a large quantity of " sleepers, this ought to more than compensate for, the small saving effected in the " metal.

" Considering all these arguments, we are unable to perceive any advantage in favour " of the inverted T rail, and therefore we must again, as we have often done before, " come to the conclusion, that the single T rail is more solid, more easy of manu- " facture in hard metal, affords a better permanent way, and one which always pre- " serves its gauge; in fine it is more economical, if maintenance, and the various ele- " ments composing it, such as sleepers, be taken into consideration.

" Let us also add, that passing trains cause less vibration to the single T system, " than to the other, owing to the greater depth of ballast used with it, and which at " the same time tends to the preservation of the sleepers.

" In laying down inverted T rails, an inclined notch is cut in every sleeper, whereas " with ours this is only done at the joints, as the chairs have a horizontal base; this " operation even with templates, is difficult to perform in practice with exactness, " and hence is liable, either to cause the rail to sit badly on the sleeper, or else to " disarrange the gauge.

" Milan, February 17th 1865."

32. These arguments are not new; their object is more especially to justify the retention of the chair-rail, in general; they pass however very lightly over that particular point, the inequality of the lower member in the single T rail, so necessary to be dwelt upon, since its advantages, if real are so much overlooked.

1° In the first place, it is a perfectly gratuitous assumption to suppose, that it is necessary to add some 8lbs. per yard, to the weight of the Vignoles rail, to give it sufficient bearing.

Farther on (44 etc.), we shall consider the ratio between the height of a rail, and the breadth of its foot.

2° As the Vignoles rail often has, at equal weights, the body as high, and frequently higher, than the single T rail, there is no reason, why the fishing of the former should be less effective, than that of the latter.

3° The inverted T rail is without doubt more difficult to bend, than the other. This, if it is a defect, is in another sense an advantage, since the lateral stiffness of the rail renders it fitter to resist the horizontal strains of the wheels; and to which Mr Montegazzo has judiciously turned his attention, on account of the sharp radii of the curves.

In the German system of railways, sharp curves certainly abound sufficiently, as for example on the line from Vienna to Trieste; and yet nowhere has the difficulty of bending the rails proved an objection to the form

adopted; nor has it ever been observed, that the operation of curving, which we shall refer to later on, has predisposed the rail to break, in consequence of the strain on the metal, towards the sides of the foot.

4° The ease with which a rail could be taken out, has been for a long time a serious objection to the chair system. The use of fish-plates by rendering the removal longer and less easy, is a security against malicious acts; and, we may add, disposes of the objection.

It is not, however, fair to go so far, as to reproach the inverted ⊤ system with the opposite defect.

If the extraction of the spikes does really require more time, screws may be used (N° 59 etc.).

5° Experience has fully decided upon the pretended necessity, for increasing with the Vignoles rail the breadth of the sleeper, lest the bottom of the rail be forced into it.

This objection, as will be shown shortly (39), is erroneous; it is in truth a very great defect in the chair-rail, and one, which has by false analogy been imputed to the inverted ⊤, but from which it is exempt, if the spikes or screws be properly placed.

6° As to the argument, drawn from the greater depth of ballast in the chair-rail system, it may just as easily be turned against it; and the saving, often considerable, in the lesser cube of ballast, made use of in favour of the inverted ⊤ one. Had this not given most abundant proofs of its stability, even at the highest speeds, as on the Northern of France, the Cologne and Minden, etc., Mr. Montegazzo's argument might be well founded : but, as this stability cannot be questioned, the lesser depth of ballast above the bearing surface of the sleepers is, without doubt an advantage gained by the Vignoles system. It is true there is the action of the layer of ballast, above the sleepers towards their preservation. The nature of this action, however, is much disputed; for it is well known, that on some railways, in Germany, and in Switzerland, the upper surface of the sleepers is left exposed; less to economize a thin layer of ballast, than because partial exposure to the air has appeared to lengthen their duration.

Any doubts which still may exist on this point, as well as the dissimilarity between observations, may be partially explained by difference of local circumstances.

33. In considering the restricted question of the relative value of the two forms of chair-rails, double-headed and single ⊤, the preference generally given

to the former appears well founded; in spite of the opinion of the engineers of the Central of Italy.

The form is more favourable to resistance; and in a wearing point of view it seems unquestionable, that at least as much, if not more, must be got out of the metal, with two rolling surfaces instead of one; in spite of the margin which it is expedient to allow for the wear of the turned surface. It can therefore be understood, that the double-headed rail may be more suited to lines at a great distance from the centre of manufacture, and where a portion of the rails can be withdrawn from use only at great expense : and if it is found, that a rail in this form possesses greater durability, than in any other, then this consideration may even overrule all others.

Thus for example, the double-headed rail has been adopted on most of the Indian railways, by engineers favourably disposed to it, no doubt for the form itself, though they advocate it less strenuously, than is the case on most of the English lines. The United States engineers, though under analogous conditions, since they still draw the greater portion of their rails from England, yet do not see a sufficient reason for adopting the double-headed form of rail. In order the more fully to utilize the metal, they cut in pieces the refuse rails, which disclose merely local damage, and this is generally the case: the sound portions welded together, and cut to the original length, give a rail capable of great durability (*).

As to inequality between the upper and lower members, on close consideration, only two arguments can be perceived in favour of it; viz. a slight economy in the weight of the chairs, and the possibility of employing a fibrous iron for the lower head. The advocates of this form lay but small stress on these two advantages, for they conduce immediately to the inverted T rail. A rail with unequal heads has sometimes been adopted under certain circumstances; but which are such as not to allow its few advocates to avail themselves of them as examples. Such is the case in Bavaria; when it was found necessary to increase the weight of the rails, the engineers being desirous to preserve the chairs of the original symmetrical rail, made the whole increase of section in the upper head and web, without altering the lower head at all.

34. The letter of Mr Delerue, above quoted (30), attempts to establish the superiority of the symmetrical rail, over the Vignoles one. In doing this

(*) Mr Riggenbach, engineer in charge of the rolling stock and permanent way on the Central of Switzerland line, has just organized at Otten a workshop for the repair of rails, on the same principle, as those he had lately seen in operation in America.

Mr Delerue laid down as a principle, " that to ensure the stability of the Vignoles rail, it is necessary to give it less height, than to the ordinary rail; " to do this would be to injure its resistance to horizontal pressure. Those sections in ordinary use, as we shall see later on (46, 47), prove that this diminution is in no way necessary; moreover, when treating of the stability of the rail, its height cannot be considered by itself, independently of the breadth of the foot.

Like Mr Montegazzo, Mr Delerue thinks, that " as the Vignoles rail rests upon the sleeper with a narrower base than that of a chair, it has a greater tendency to force itself into it ".

" Another reason " he adds " is that, during the passage of the train, this rail has " such a tendency to turn over outwards, that on certain lines, the spikes on the inside " have been drawn out.

" This tendency to turn over causes the whole weight to be borne by the outside " edge of the foot of the rail, which then has a strong disposition to force itself into " the wood.

" In the chair system, the tendency to overturn is greatly diminished, and the chair " is more disposed to slip, and not to turn over on its outer edge; hence a far greater " steadiness.

" On the older lines of Versailles and of Saint-Germain chairs have been found, " which, after having been down for fifteen years, could have been drawn by hand, " yet no cases of running off the rails have been caused thereby.

" A Vignoles rail, on the contrary, placed upon rotten sleepers would have offered " no stability. " (Page 11, of printed letter, about quoted.)

No one certainly will deny the last assertion : it appears however no less undeniable, that with decayed sleepers, both the chair-rail, and the Vignoles rail are equally worthless, and not to be trusted. If the state of things, of which Mr Delerue speaks, could have continued for a certain length of time without any unfortunate esults, it was on short lines, travelled over at low speeds; and there is no reason to believe, that that condition would have been any more serious with an inverted ⊤ rail. No one, and Mr Delerue least of all, will pretend that chairs allow the use of rotten sleepers with impunity; so that the example quoted is in no way an argument either for or against the rail.

As to the distribution of the weight upon the foot of the inverted ⊤ rail, it is certain, that it ceases to be uniform, as soon as the thrust of the wheel-flange introduces a horizontal element; the greatest pressure by unit of surface then exists on the outside edge. Everything however lies in the knowledge of the limits within which this concentration of pressure really works. According to Mr Delerue, the momentum of overturning, which is due to the thrust of the

flange, increases, till it exceeds the momentum of stability due to the vertical weight, so that the rail turns over upon the outside edge of its foot, drawing the spikes inside. It is to be regretted that the lines, on which these effects were noticed, have not been specially named. The rail has been observed in certain cases to have slipped transversely, but never to have turned over, at least to my knowledge. It might no doubt happen with other proportions, but not with those sections now in use, even with the most elongated. It is difficult therefore to perceive in this objection, more than a mere theoretical grievance.

35. The chair-rail has up to the present been used almost exclusively in England, and the unfavourable conditions under which the Vignoles rail has been put in operation on the London Chatham and Dover, and on the Metropolitan line, are little calculated to remove the prejudices against it.

Lengthened custom, and the interest which the foundries have in retaining a portion for themselves in the formation of lines, are no doubt connected with the preference acquired by the chair-rail.

36. It is, at least the symmetrical rail which predominates in that country; not so however in Belgium; for it affords an example of most pertinacious adherence to the rail with unequal heads. The board of direction of the State Railway made in 1863 a trial of symmetrical headed rails of 77 lbs. to the yard : previously, in 1860, in consequence of the success of the Vignoles rail on the Northern of France, it had been decided to make use of a section of this type on a sufficiently large scale (Pl. II, fig. 5); the result however of the trial was only to restore the original form, non-symmetrical, of 69 lbs. to the yard (fig. 3); yet one cannot give with certainty the reasons far this determination, for the engineers appeared generally favourable to the inverted ⊤ rail.

The example of the State Railway has up to the present time carried with it the greater part of the private companies, who preserve the non-symmetrical rail of 69 lbs. as their type. There are only two exceptions: one, as a matter of course, applies to that portion of the Northern of Belgium Railway worked by the Northern of France, which naturally adopted in Belgium that rail, which gave such good results in France (Plate III, fig. 13). The other dissenting company is the Luxemburg, which had also at first adopted the official rail of 69 lbs. This rail, whose average life was only from seven to eight years, has been completely abandoned, and replaced by an inverted ⊤ rail, the weight of which is as much as 81 lbs, per yard, on account of the frequent gradients of 1 in 60 occurring on this line.

37. *Inconvenience of chairs.* The chairs form an important item of expense; at the present price they cost more than £ 300 per mile of double way. The inutility of this expense ought of itself to be a sufficient argument; it is not however the only one, far from it, for chairs are brittle things, a merely partial running off the line will often break hundreds of them (*).

Hence they may be the means of causing damage to the rolling stock, and convert into a serious accident, what without them would be harmless.

Even had not experience proved it, we might perceive in the wooden keys, which the chair-rails require, an essential element for the well-being of the line, and of importance in opposing a compressible body to the pressure of the wheel-flange against the rail : however we now know, that if this interposition is really necessary, it is solely for the sake of the chair itself, to protect its outside cheek against sudden shocks (**).

In reality, by separating at the same time the fragile and the compressible body, neither the connection of the other elements of the road, nor the easy motion of travelling, have been in any way interfered with.

If however the compressibility of the keys be not an important argument, it is clear that the serious inconvenience of this addition, as well as of the chair, is not recompensed by any advantage : for with the exception of the wedge being required, and the very serious fact of want of unity, the chair system and the American one amount in fact to the same; the foot of the rail being fastened to its supports, or having the means of being so, exactly as its equivalent, the bottom of the chair. There is but one point of difference; it is that, with the chair, lateral motion on the part of the rail is prevented by both bolts; whereas when without the chair, it is the outside one alone which resists this strain : but it is easy, whatever importance be attached thereto; to secure at a very small cost the firm grip of the bolts; a firmness more apparent, however, in many cases, than real, as far as concerns the simultaneousness of their resistance.

We shall again refer to this point, whilst considering the laying out of curves.

(*) One example alone will suffice. On the 5th of March 1866 the engine of the mail-train from Mulhousen to Paris got its hind wheels off the rails near Rolampont (Upper Marne). The guard, whose attention had been aroused by the unusual noise and the flying about of the ballast, in vain signalled the driver to stop, who, not noticing anything extraordinary in the progress of his engine, held on his way, and finally stopped at Rolampont. 1,235 chairs were broken; this series of breakages commenced at a rail, broken either by the mail-train, or by the preceding one and which had been the cause of the wheels leaving the rails.

(**) It does not appear that the breakage of the cheeks of the chairs is more frequent, either on lines where the wooden wedges are inside, or on those where the rail, single-headed, is closed up with an iron key.

As to the tendency of the rail to overturn, it is certain, that if the same *theoretical* stability is desired for a broad based rail, as for the one confined within chairs; that is to say, in preserving the same ratio between the half-width, and the total height, the metal would perforce be distributed in a manner little favourable to vertical pressure. But the considerations, upon which the ratio of the chair-rail is based, are entirely apart from its stability, properly speaking; the breadth of the hollow of the chair, especially for the symmetrical rail; the thickness at the base of the ribs, which stiffen the cheeks; the diameter of the bolt-holes; and the thickness to be given outside them, all tend to give the shoe a much greater breadth, than its stability requires. The complete inutility of so great a ratio between the leverage of stability, and of overturning is established in a conclusive manner by other, than the very uncertain calculation of the horizontal strains; viz., by direct observation of lines using the Vignoles rail. It has never been remarked, even in those rails where this ratio is most unfavourable, that the spikes placed on the inside of the foot were more subject to be torn out, than those which fix the bottom of the chair. This rail therefore possesses in itself, in spite of the excessive ratio of the height to the half breadth of the base, sufficient stability to prevent the longitudinal resistance of the inside spikes being ever seriously called into play. This is easily understood; for allowing even that a wheel, relieved for a moment from a portion of its normal burden in consequence of the oscillation of the engine, and pressing with its tire against the rail, tends by this means to overturn it, it would also immediately seek to prevent this motion, which could not happen without the rail being raised. We shall treat later on (59) of the arrangement of the spikes.

38. On some lines of double way, take for example the Western of France, the axis of the chairs is placed about 1″ nearer to the coming train, than that of the sleeper. This arrangement is in order to prevent the turning over of the latter, which generally has a tendency to a position of equilibrium inclined in the direction in which the train is going. Some engineers have hence concluded that, even on rails, which are not fished, the wheels do not cause any shock to the end of the rail which they reach last, or lower end. This is a manifest error, and to be convinced of this it is only necessary to observe what takes place under the influence of a train passing slowly.

On examining the line when at rest, the lower end of the rail does really seem to be protected by the inclination, which is then *towards it;* nevertheless the moment a wheel approaches the joint the inclination is *from it*, the sleeper being inclined towards the side whence the weight comes, till it is reached

by it: and, when past it, then becomes inclined in the contrary direction, that is always towards the weight. If this inclination be observed in a marked way, it is simply because it is the last effect produced; it has effaced the first, which has none the less taken place however. The utility of placing the axis of the chairs apart from that of the sleepers, as far as regards the stability of the latter, appears therefore to be at least questionable.

39. Among the inconveniences of chairs, one of the greatest, and to which I have alluded higher up, has been made use of, as the basis of a very unjust accusation against the Vignoles rail. In spite of their broad foot, chairs penetrate quickly into the wood, especially if it is of a soft description; and hence it was predicted, that the same effect must certainly take place, and much more quickly too with the inverted **T** rail, of considerably less width than the chair, and that it would be indispensable to interpose a metal plate for the protection of the sleeper.

The example of the German lines, where plates are used only at the joints, unless in curves of small radii; and especially that of the Northern of France, where there are no plates at all, not even at the joints, ought long ago to have disproved an objection founded upon neither complete, nor exact observations of what takes place on a way laid with chairs.

In the majority of chairs it is the custom to design the lower part of the inside cheek exactly according to the form of the head, in order that when this last is fitted in the hollow of the cheek, under the horizontal pressure brought to bear upon it by the wedge, the base of the rail may by this alone be in contact with the bottom of the chair. But this exact coincidence presupposes in the form of the rail, and of the chair, a precision, and an uniformity very difficult to be effected, or at least to be preserved. The cavity of the chair must receive heads, which are more or less deformed, or the returning of a double-headed rail would be often impossible. The idea of making the inside cheek turn completely back over the lower head, in which case it no longer presses it against the bottom, has often been abandoned.

The new chair of the Western of France line, for example (Pl. I, fig. 5) is of this sort. It does not pretend, and justly so, to a perfect coincidence, which practice shows to be impossible. The duty of the key therefore is not only to press the rail against the inside cheek of the chair, but also, or rather it should be, to keep the lower head in contact with the bottom of the cavity. But how is it possible to count upon the efficacy of a system of keying up, which has to undergo not only various mechanical actions to which the road is subject, but also the incessant variations of the atmosphere; and which

would, so to speak, constantly require the aid of man to combat these disturbing elements. Let the sun shine, the damp air becomes dry; and the wedge, even supposing it to have been keyed afresh before the change, is tight no longer. Once this takes place, in spite of the curving often given towards the top of the outside jaw of the chair, and of the elasticity of the wedge, the bottom of the rail is no longer pressed against the chair. The same takes place, if the wedge, tightening the body of the rail, becomes worn or injured on its lower face; the chair and the rail may then separate from one another, and they do so in effect, if the sleeper, less packed than its neighbours droop ever so little. Under these circumstances the rail, when reached by an engine-wheel directly over the chair, is thrown sharply against it, which transmits the blow to the sleeper; and it is this series of blows, incessant and violent in spite of the slight distance of their fall, which disarranges the sleepers. In fact, if a close contact exists at half the supports between the bottom of the rail and the chairs, it may be looked upon as lucky. Thus at once the damage may be explained, which is done to the notches in the sleepers; to the rails at their points of support, which in reality, as is well known, is one of the principal obstacles to the custom of turning them not becoming more common; and also of the frequent fracture of the bottoms of the chairs; unless a thickness apparently greatly exaggerated, about two inches, is given to them; and which really would be out of proportion, if they had only, as ought to be the case, to support a simple burden, instead of being exposed to incessant blows.

Let the rail be constantly kept in contact with its supports, so as not to acquire any motion independently from them, and all these effects disappear.

But it is precisely this condition, almost impossible to fulfil with the chair and wedge, which is complied with most naturally in the Vignoles rail; provided, be it understood, that it be laid properly, and that the projecting heads of the spikes retain the foot exactly in its place, in the notch; then there will be no longer any blows. Thus is the fact explained, that, all else apart, the broad foot presses itself far less into the sleeper, than does the chair with its greater bearing surface.

40. It should be cited, as an inconvenience on the part of the chair and wedge, that they are ineffective against the longitudinal dragging of the rails. The examination of this point will naturally find its place at the end of the discussion on the various means of fastening, and on the strengthening of the joints (105).

41. The Vignoles rail has been applied on the aforesaid London Chatham and Dover Railway; but, in an odd way. The rail rests on a strong cast iron shoe, with raised edges; iron brackets fastened with bolts hold the foot down on this species of rude chair. It is evidently a gratuitous complication directed against imaginary danger.

Had the only object been the firm hold of the two bolts against lateral slipping of the rail in curves, a simple strip of wrought iron would have sufficed for the purpose.

An analogous arrangement has been used, but only at the joints, in Bavaria; where there exist examples of every kind of permanent way known, excepting however on longitudinal balks.

42. The increased length of bearing of the rail on the sleeper is one of the most useful consequences of the suppression of the chair. Some engineers have thought, that in this there was, both a compensation in the lesser breadth of the foot, compared with that of the chair, and a diminution in the effective span, equal to the distance between the axes of the sleepers. It is not however here that one must look for the true advantages of the Vignoles rail, and the explanation of its success.

The rail does certainly bear upon the whole width of the sleeper, but there is no reason for all that to suppose, that the pressure is uniformly distributed over the whole surface, or that the effective bearing span of the rail is reduced to the distance from edge to edge of the sleepers. This would be granting to these last a lateral stability which they are far from possessing.

For, in bending towards the weight, they turn on their longitudinal axis; and this effect ought even to be more marked in this system than with the chair, which transmits the weight more or less in the mean plane of the sleeper, unless this condition be purposely departed from (37). It might therefore, till proof of the contrary, be feared, that in this lay a special cause of instability for the inverted **T** line, or at least an increase of expense for maintenance; it is not so. If the sleepers last well under the immediate action of the rail, without being protected by a metal plate, it is owing to the close contact of the two surfaces, and not to the length of bearing : when however the sleepers get damaged, without its resulting from the soft nature of the wood, or the too great weight per wheel, it is the maintenance, which is at fault in not fulfilling the primary condition of contact betwen the rail and the sleeper.

43. To sum up, one may claim for the Vignoles rail a considerable economy in first cost, and in maintenance properly so called; a resistance to

breaking at least equal, or certainly greater, according as the comparison is, either with the double-headed rail, or with the single T; a more complete security; and a steadiness for the wheels, practically equal to that of the chair-rail. There is but one point we cannot yet speak upon with certainty, the length of its wearing power.

As the head of the inverted T rail ought to be identical with those of the double-headed one of the same weight, it may be maintained, not without some show of reason, that the latter would last longer than the former; it being sufficient to turn it, whilst the former requires to be replaced by a new one. Granting this advantage, it cannot however be weighed, even on the score of simple economy, against those which the Vignoles rail possesses.

It is far less in reality, than appears at first; for the lower member of the double-headed rail also becomes worn, directly over the chairs, for the reason which has just been shown (39); without reckoning, that by this fact the final destruction of the upper head is necessarily much more rapid than in the other form.

In the minds of engineers, who might have been tempted to make use of it in France, the inverted T rail remained for a long while under the weight of an attempted trial, made many years ago on the Saint-Germain line.

The extended use of it, made bit by bit on an immense scale, and with a success so well known, has not been able to dispel the impression produced by a solitary trial, incomplete and since become utterly insignificant by the fact alone of the remoteness of time. Prejudices founded upon an argument of so little weight were combined with custom, and with a sort of systematic indifference towards German railways, which were looked upon at first in France, as lines of a somewhat inferior order, after the fashion of those of America.

A prejudice, unjust in itself, and vexatious in its consequences. For the railways of Prussia, Hanover, Saxony, etc., may be quoted as among the best that exist. Doubtless their excellent condition results partly from local causes, from the numerous maintenance staff, and from the low speed of the traffic: to their system of construction, however, it must certainly in great measure be also due.

At the close of this discussion we must remember, or in these matters it is always to experience itself we must turn, that if the double-headed rail has been completely abandoned in Germany, it is after a long trial; and after being extensively tried upon a great number of lines; the single T was so on the Dusseldorf to Elberfeld, on the Berlin to Potsdam, on the We phalian, etc. Both one and the other have disappeared to make roor

the Vignoles rail; and rarely is the chair-rail to be found, except in Bavaria, and on the line from Potsdam to Magdeburg. It daily loses ground in France, it is rejected in Spain, Russia, and Holland, and in England it begins to be questioned. The broad-footed rail has long been in use in this country, and used during the construction of works under the name of the contractors' rail. This use, instead of calling attention to it, appears on the contrary to have thrown discredit upon it; by classing it in the list of imperfect tools, and fit only for temporary lines.

Without urging further the superiority of the Vignoles rail, to my mind, amply demonstrated, I pass to the examination of the proper proportions to be given to it.

§ II. — Proportions of the broad-base rail.

44. Now-a-days, on long lines, the weight per yard varies but little; in England it reaches 80 lbs. and even 92 lbs. (London and North Western); it ranges generally between 70 lbs. and 77 lbs. This last figure is seldom exceeded except on inclines of 1 in 60 at least, as on the Luxemburg line (35); moreover the rapid destruction of the rail is sought to be counteracted, rather by using a tougher metal, than by increasing the weight. But this approach to unanimity is far from being extended to the form of the rail.

To determine the proportions of the chair-rail, the two heads are first of all assigned a section, and a distance from each other, in proportion to the weight of the rolling stock; the web then only requires sufficient thickness to ensure unison in the deflection of the heads; so that it may not give way at the points of support. This will provide ample resistance to any vertical shearing strains; likewise horizontal stiffness, the more so, as the rail is supported by the jaws of the chairs. As to stability of rotation, it is needless to take further notice of it; for it is more than amply ensured, despite the thickness of the bottom of the chair, by the great breadth which it requires.

Such is not the case with the Vignoles rail: the areas, practically equal, of the head and the foot, and the breadth of the latter, being given, the body must be sufficiently thick, and at the same time be so limited in height, as to endanger neither the unison between the upper and lower members, nor the solidity of rotation of the rail. The experiments already quoted prove, that the former risk is remote; as to the latter point, it is only by guesswork, that a limit of height suitable to the given breadth of base, can be fixed.

If is evident moreover, that the ratio we are now treating of cannot be an invariable one.

If there is such a thing as a primary truth, although often overlooked in practice, it is, that all the mechanical elements of a railway are closely connected, and ought to be decided upon relatively to one another.

If it is true, that the weight of the rails ought to depend on the weight of the engines and their speed, on the section of the tires, as well as on the relative thicknesses of the spokes and of the flanges, on the nature of the line, and on the distance between the axle-trees, it is no less certain, that upon these two last elements ought also to depend the ratio between the total height of the rail and the breadth of its base : canting the rail preserves the equilibrium against centrifugal force; nevertheless the rails in curves receive very considerable horizontal strains in consequence of the axle-trees being parallel.

The connexion just spoken of is clearly controverted, more especially on the German lines : proceeding from North to South, it may be remarked that at first elongated sections prevail, and that gradually the rails become lower and lower, to become at last decidedly compact in form : this height actually varies from 4 to 5 inches.

As examples at either extreme of this scale may be cited, on one side the rail, new type, of the Cologne to Minden, and of the Eastern of France lines (Pl. II, *fig.* 9); and on the other that of the Northern of Austria, and the old rail of the Semering line (fig. 14). This gradual diminution in height was, up to a certain point, the natural consequence of the course followed by the line, that is of the nature of the country; generally level towards the north, but mountainous in the south. It moreover partly results from the course of progress in Germany, which in railway matters has been from north to south. The older forms, low with a thick web, have almost everywhere given way to more elongated sections. By comparing, for example, the broad-base rail, first in use on the Leipzig and Dresden (Pl. IV, fig. 33), with that of the Eastern of Prussia, or of the Cologne to Minden, it may be seen how far they are, now-a-day in the north of Germany, from the proportions at first adopted.

The same is the case in Austria (Southern Railway, Pl. II, *fig.* 14, and 16; State Railway Pl. V, *fig.* 33) ; on the Central of Switzerland (*fig.* 10), etc. The very short and thick rail of the Tudela and Bilbao, in Spain (Pl. II, *fig.* 26), approaches in its proportions very much to the old rail of the Semering, and is an exception to other lines of modern date.

45. The breadth of the foot was at first restricted by reasons of manufacture. Its cooling, more and more rapid as it became thinner by passing through the grooves of the rolls, and especially the great depth of those grooves which formed the foot, was for a length of time a source of consi-

derable difficulty: moreover at the foundries it was not without much trouble that rails were rolled with the lower member sound, free from blisters or cracks. If, by a more marked increase in the size of the foot, it was desirable in the inverted T rail to cause the difficulty, purely theoretical on the score of stability, to disappear, it would be necessary, apart from the question of manufacture, to increase the quantity of metal therein; for there is evidently a minimum thickness, below which the sides would no longer deflect in unison with the rest of the section. This is exactly what Mr. Weishaupt has proved, by testing in a lever press the rails of the lines of the Lower Silesia, of the Berlin and Hamburg, and of the Eastern of Prussia railways: in an upright position (Pl. II, *fig.* 20), the cross section of the foot on the underside becomes convex in the centre, as the deflection at the edges takes place later, than over the rest of the section. In an inverted position (*fig.* 6 and 7) however, it becomes concave, as the sides, being no longer sustained by the web, themselves give way; first through the immediate action of the weight, also, and more especially, under the compressive longitudinal strain, to which, owing to their form, they offer but a poor resistance; thus they here yield more than the body of the rail, instead of less as in the first case. This curvature of the foot does not show itself, it is true, in an apparent manner except under a very great weight, and in rails made with fibrous, or tensile iron. But, as it is precisely this quality of iron, that is often desired for the foot, caution must be used, lest by making it too thin, its unity of deflection, and hence its resistance to transverse strain be not impaired. A certain care must also, for the same reason be taken in regard to diminishing the thickness of the web.

The rails of the Eastern of Prussia experimented upon by Mr. Weishaupt were $\frac{5}{8}''$ in thickness in the body; he considers, however, that this would be better reduced to $\frac{1}{2}''$ inch; slightly lengthening the web, and distributing between the head and the foot any excess of metal: however a reduction, allowable in a hard iron, might prove inconvenient in a soft species; it is therefore difficult to fix a thickness for the web, independent of the nature of the pile, over which one has not always control. Though only natural to mass the metal in the head, and the foot, care must be taken not to thin the body too much, and thus expose it to give way under its load. It must not, moreover, be forgotten, that, though the strains of tension and compression are null in the layer of neutral fibres, it is there that the slipping, or shearing strains, on the contrary, attain their maximum; so that a too great contraction in the centre of the web, might if there was any flaw in the welding at that point, cause a rupture more or less serious.

46. The form of the rail has been for many years the object of deep discussion, accompanied by constant observation on the part of the engineers of the Cologne and Minden railway, which is very justly looked upon, as one of the best worked lines on the Continent: four different sections have already been in use; and it is remarkable, that the latter ones, instead of increasing in weight, as is usually the case, are lighter than the preceding, though the sleepers have not been augmented in number.

		HEIGHT.	BREADTH of foot.	RATIO between height and half-breadth.	THICKNESS of body.	WIDTH of head.	WEIGHT per yard run.
		ins.	ins.		ins.	ins.	lbs.
Cologne and Minden.	1st form.	3 3/4	3 15/16	1·89	5/8	2 1/8	57
	2nd form.	4 3/8	3 3/4	2·31	3/4	2 3/8	72
	3rd form.	4 7/8	3 5/8	2·71	[illegible]/16	2 3/16	65 1/4
	4th form.	5 1/8	3 15/16	2·60	[illegible]/2	2 3/16	(a)

(a) The exact weight is wanting, but it can differ very little from N° 3.

It is clear, that the engineers of this line were not afraid of progress; first the height is increased, then the breadth of the foot is diminished, the same is done with the web, and finally, in the third example, the weight is also decreased.

No doubt the experience, which preceded each of these changes, was open to the inevitable objection of having fulfilled, but poorly, the conditions required of a rail in actual use: it was however, less from this experience, of but short duration, than from close and lengthened attention to their line, that these engineers acquired that information, which they embodied in these successive changes of form, and in the conviction of their ultimate success, which has been so completely borne out by subsequent facts.

47. Mr. Weishaupt, as a conclusion to his investigations on this head, proposed the two following types of rail: they are worth quoting, not as models of proportions, applicable in every case; but as examples of a well considered distribution of metal, for lines having only curves of considerable radius.

	HEIGHT.	BREADTH of foot.	RATIO between height and half-breadth.	WIDTH of head.	THICKNESS of body.	WEIGHT per yard run.
	ins.	ins.		ins.	ins.	lbs.
N° 1.	$4\,^5/_8$	$3\,^1/_2$	2·62	$2\,^5/_{16}$	$^1/_2$	»
N° 2.	$5\,^1/_8$	$3\,^1/_2$	2·91	$3\,^5/_{16}$	$^9/_{16}$	$66\,^3/_4$

These sections, based on equality between the elementary resisting forces, do not afford equal moments of inertia, on either side of the horizontal axis, passing through their centres of gravity. There is a difference of about $\frac{1}{10}$ in favour of the upper part, which is intended to compensate for the wear, in use, of the head. The ratio of the areas is very nearly the same, as that of the moments.

The ratio of 2.91, of the height to the half-breadth, is perhaps somewhat excessive, but this example proves at least, what little importance competent men in Germany, during the last fifteen years have attached to an objection to the Vignoles rail, which is still adhered to by certain engineers; viz. its tendency to overturn, and experience has fully confirmed their selection. In determining the section of a rail, all the elements peculiar to it ought to be discussed and taken into account. This discussion is always necessary; but more especially for the inverted ⊤ rail, than for the double-headed one, which has not in itself to comply with so many conditions.

It would be a loss of time here to describe all the numerous forms of rails; it will be sufficient to state their intended object, and the causes thereof. There are no doubt certain ones, even among those to which much attention has been paid, which fail in some one point; for example, it is difficult to suppose that the high slender rail of the Cologne and Minden railway, and the low compact one of the Bilbao and Tudela line (Pl. II, fig. 26), could be both designed to meet the same requirements; possibly, in the former case too great an importance was attached to vertical resistance; and in the latter horizontal resistance, and, more especially, stability of rotation were considered paramount.

In the present state of the question the N° 1 rail of Mr. Weishaupt, and that of the Northern of France railway (Pl. III, fig. 13), which has been adopted by several lines, would appear to possess proportions well fitted for lines with curves of large radius. The section adopted by the Eastern of France line, since 1863 (Pl. III, fig. 12), likewise deserves mention; principally because the modifications made in the original rail, were suggested by actual experience.

Passing over that portion in the general design, particularly affecting the joints and the fish-plates (see 82-83), and which was retained to allow of the new rail being substituted for the old one, in places requiring but small amount of repairs, we may say, that the sides of the head are better supported; the thickness of the web was reduced from $\frac{11}{16}''$ to $\frac{5}{8}''$ and the edges of the foot were made flatter, to allow a better bearing for the heads of the screws : in fact, in the new rail, the weight was lessened from $72\frac{1}{2}$ lbs per yard to $70\frac{1}{4}$ lbs, while the vertical resistance was slightly increased. The ratio of the height to the half-width is 2·38, on the Northern line; and 2·42 on the Eastern, which is therefore satisfactory for this latter form.

Up to the present time the apparently excessive boldness, evinced in the third type of the Cologne and Minden line, on which the speed attained is as great, as anywhere else, has given no cause for regretting it.

The rail of the London Chatham and Dover line, already quoted, is somewhat slender; the difference however between the breadth of the foot and the height is still more striking upon another English railway, the Metropolitan, where the inverted ⊤ rail has also been adopted : the section used here was designed likewise, under the influence of the same fear, to prevent the rail being forced into the sleeper : in this case there was real danger, for the rail was laid on longitudinal balks; and having before them the not very encouraging example of the Great Western railway, on which the wear of the balks is very great, in spite of the great breadth of the bridge-rail, it was but natural, that the engineers should wish to guard against the same result. This point will be again referred to, when we come to treat of longitudinal supports (127).

48. ***Rails in use in the United States.***

On the other side of the Atlantic there is a singular diversity in the proportions of the section, as well as in the weight of the rails. Nevertheless light, and short compact ones, are the forms, which generally predominate. On the New York and Erie railway, the weight has been gradually increased nearly 50 %, from 55 to 75 lbs per yard; and, according to Mr A. Holley (*), the heaviest rails have invariably been the worst. On the Camden and Amboy railway, after employing a rail 7″ high, with but poor results, it was discarded for one $4\frac{1}{2}''$ high; which is very serviceable.

In the eyes of the author just quoted, light rails, with a very short body, are not only of superior quality, owing to a more forcible compression of the metal, and a more favourable ratio between the contour, and the area of sec-

(*) " American and European railway practice ". — New York, 1861.

tion; but they are also better suited to the generally imperfect condition of the American railways, arising from the insufficient depth, and poor quality of the ballast; from the very slender dimensions of the sleepers; and from negligence in the maintenance of the permanent way. It may be easily understood how a flexible rail may, as it were, adjust itself to the inequalities of its supports, and that such a circumstance, though clearly inadmissible on our railways, where great speed is required, may be suited to the United States lines, where the speed is low, and the rolling stock, by its special construction, is better adapted than ours, to undulations in the level of the line. It is only by taking this amount of flexibility into consideration, that we can understand those compact forms, with a large head, and a very short body, so common on the other side of the Atlantic, and which are called pear-headed (Pl. VI, fig. 10, 11).

§ III. — Convexity of the head.

49. Convexity, in the rolling surface of the head, is still almost general; the radius is usually 8″, which is that of the new inverted **T** rail of the Eastern of France line (47); whereas in the old form, it was only 4″. At present it is seldom reduced below 6″, and never less than 5″, the lowest limit fixed for the German railways, at the Dresden meeting: in England however a much lower figure has been often employed, even 2″½; and some engineers, did they not fear greatly to increase the wear of the line, would do so again.

Nothing however appears to warrant the importance, which is so generally attached, especially in England, to the convexity of the rolling surface; the first English rails had their head flat, and 2″½ broad; the form having naturally given very poor results, was somewhat hastily condemned; while the fault lay only in the excess in the flat portion of the rolling surface. If considerable convexity is advantageous, the reason lies in the restriction of the bearing surface, of the tires, to a comparatively narrow zone in the centre of the head; as it thereby does away with any slipping, which the conical form of the tire might produce, if that surface were greater; and more especially does it remove the unsupported sides of the head from the immediate action of the load. This latter condition ought to be fulfilled, not only when the tires are new, but also when their section is a little altered, as much by real wear and tear, as by the working up of the metal towards the outside. If the head is too flat, the rim thus formed throws the load on the outside of the head; and the rail wears out much sooner, than if it is applied on the inside edge; as in the former case, the force presses outward, where there is nothing to resist

it; whilst in the latter, it is against the inside of the rail that it is urged; on this account it is, that rails often cannot be turned, the exterior edge being too much worn out of shape to be placed on the inside of the line, and submitted to the action of the flanges of the wheels.

To counteract this cause of wear, which a proper maintenance of the line ought to confine within very narrow limits, it is by no means necessary to increase the convexity of the central portion of the head; indeed, provided it be not too broad, and the curvature of the surfaces on either side be sufficiently marked, it may be made quite flat; it is only necessary, that the edges should round off rapidly.

Take, for example, the 73 lbs unequal-headed rail of the Mediterranean railway; a tangent of $\frac{3}{8}''$, at the centre, is joined at either side by a curve composed successively of the following radii, $2\frac{3}{4}''$, $\frac{5}{8}''$, $\frac{7}{16}''$: in the double-headed one, in use on the Orleans railway, an arc of $4\frac{1}{2}''$ radius, subtending an angle of $30°$, the chord being $1\frac{3}{4}''$ long, at the centre, joins on each side with an arc of $\frac{5}{16}''$ radius; the ordinate of an arc of a $4\frac{1}{2}''$ radius and $\frac{3}{8}''$ long is only $\frac{1}{20}''$. If these two sections be placed one over the other, it will be seen, that if they coincide at the centre, the sides will do so also; so that, in both rails, the non-supported parts are nearly equally removed from the action of the tires. The first section is preferable to the second, because it distributes the pressures more equally, without making the circle of contact too large, and at the same time it relieves the sides of the head; the special duty of which is to give transverse resistance to the rail. If, for instance, the mean radius be lowered to $2\frac{1}{2}''$, the ordinate becomes $\frac{2}{25}''$, and the edges of the rail can only then be protected by an excessive concentration of pressure, which is certainly not necessary, for their protection from the direct action of the tires; and which must certainly lead to the very opposite result, by increasing the wear, or, in fact, leading to the crushing in of the central part.

To be convinced of the insignificance of many details, which are frequently the subject of much consideration, we have only to notice the irregularity of the changes, which soon alter the section of the head, even in rails of good quality. To design the very best theoretical section is, if considered minutely, but a problem involving loss of time; the only essential condition is the combination of a broad surface of contact, with a sufficient depth of head; if this condition be not fulfilled, the tires, in spite of the chamfer made upon them, soon bear on the exterior edge of the head, the destruction of which is much more rapid, than that of the interior one, in spite of the action of the flanges; which is easily seen on rails where the convexity is too slight; no matter what may be the details of their design.

50. The same result might likewise take place with very flat rails, through a slight excess of inclination (55); and this ought to be taken into consideration, in laying the permanent way on lines with many curves, and consequently with very conical wheels: if the depth of the head is not sufficient, the circulation of the rolling-stock belonging to railways, with curves of greater radii, and with wheels less conical, would greatly injure the rails, on account of their excessive inclination, bearing against the conical surface of the tires; it would perhaps in this case be judicious to give the rail an inclination, but slightly inferior to the conicity of its own rolling-stock; for the main point should certainly be to prevent the tires from bearing upon the exterior edge.

This want of unison between the inclination, and the conicity, to a certain extent exists on the Semering line; the conicity of the engine wheels, specially intended for the service of this section, is greater, than that of the waggons which are used over the whole line; the inclination of the rails having been determined in keeping with the smaller slope.

51. A form of rail, with which great care was taken in 1856, viz. that of the Eastern of Prussia, called the "Normal section" or the "Ministerial rail" (Pl. II, fig. 9), has been since modified in accordance with the preceding remarks; and adopted on the Dutch railways in 1863, the only difference being, a slight increase of thickness in the web. Experience proves that the original rail, which long found favour in Prussia, really fulfilled the requisite conditions of resistance, and stability; it was however found advisable to diminish the curvature at the top, not only to ensure an equal distribution of the load, without however making the surface of contact too large; but also to ensure, during its passage through the rolls, a more forcible compression of the metal in this part; upon this however the effect produced by the suppression of the convexity of the rail is but slight. Whatever may be the details of the final section, the duty of the finishing rolls, through which the rail passes, is but of secondary importance, as far as the compression of the metal in the region of the rolling surface is concerned. The height of the rail certainly increases somewhat, $\frac{1}{25}''$ to $\frac{2}{25}''$, at each roll it passes through, which is at the cost of the compression, taken in the above sense; but this result is almost independent of the convexity of the rolling surface. As it is certain, that this convexity is worn away by usage, where the breaks are used frequently, to the detriment of the tires, it seems only natural, that a more durable form should be adopted at the outset. Though there may be some difference, yet not much, as to the breadth desirable for the rolling surface, it can hardly be disputed that it is advantageous to make it flat. Convexity generally however prevails; there is on some Ger-

man railways, a decided tendency even to increase it, contrary to the example just cited. For instance, the radius of the rolling surface is only $4\frac{7}{8}''$ in the Austrian new Bessemer steel rail (Pl. III, fig. 12); while on the other hand the rail of "Gebirgs-Bahn" (*) in Silesia (Pl. V, fig. 28) has a tangent of $1\frac{1}{4}''$ long, joined on each side by an arc, forming a complete quarter of a circle, and having a radius of $\frac{9}{16}''$; the length of the straight part appears somewhat too great.

52. In Germany Mr Daelen has recently proposed a rail (Pl. II, fig. 18), where the head, quite flat, is widened out and terminated by an upright face on the outside, in order to increase the surface of contact; giving at the same time the inclination necessary. Symmetry of form, and consequently the power of turning the rail, are thus sacrificed; this form, instead of the theoretical advantage, which it proposes, would entail inconveniences of every kind; as is fully proved by the experience of the first rail of the Paris and Saint-Germain railway, which was of a similar shape.

53. Two difficulties arise with regard to the breadth of the bearing surface for the wheels; when it is too large, it calls into play the injurious effects of the conical form of the tires, and worse still those of the plate-laying, or of the maintenance; when too small, it concentrates the pressure upon such a reduced surface, that the metal gets distorted, and crushed, through its contact with the wheels.

It is difficult to determine, in every case, the limit attained by these pressures, and the share, which they have in the alterations of the head of the rail; but it is certain, that these alterations do not only proceed, 1st from the tension of the outer fibres of the rail, considered as a solid body, deflected transversely; 2nd from the slipping of the tires, owing to the connexion of the wheels, when locked, and of the engine wheels which are coupled; 3rd from the tangential pressure of the driving-wheels; 4th from want of grip; 5th from the pressure and slipping of the flanges, and from the transverse slip of the tires in curves; but that they also arise from the direct action of the load upon the points of application; from the concentration, in fact, of the pressures upon a very small surface, and smaller in proportion, as the diameter of the wheels is reduced.

Under these considerations a heavy, stiff, rail suffers more, than a light one;

(*) In Prussia they term " mountain railways " certain lines, which would be elsewhere considered to have merely moderate inclines: on the greater part of this secondary system in Silesia, the inclines do not exceed 1 in 100; only on the branch from Dittersbach to Waldenburg, is it as much as 1 in 70; the curves are generally of 37 chains radius, and are only exceptionally decreased to half this amount.

because the latter, being more flexible, takes in a greater arc of the wheel, and thus distributes the pressure, though very unevenly, over a more extended area.

54. In the absence of exact valuation, which is impossible with such complex actions, the frequent exaggeration, in this point of view, of the load on the rails has been proved, in an undeniable manner, by the crushing of the tires; and fortunately so, for here there is no complication, which could render it doubtful, as with the rail: it is this rapid destruction of the tires, rather than of the rails, which opened the eyes of engineers in charge of the rolling-stock, and induced them to discontinue the use of such excessive loads, by increasing, where required, the points of support in the engines: thus the permanent way has reaped a benefit, which was not intended for it.

It is generally admitted, that rails of good quality, weighing 72 to 75 lbs per yard, can support, without any derangement of the metal, a load of from 10 to 11 tons per axle, which is the limit not exceeded ordinarily, unless for engines with non-coupled wheels, where the necessity of adhesion requires that weight to be considerably surpassed. Thus in the opinion of the engineers of the Northern of France railway, their line is not at present over weighted; and 75 lb rails suffice for the work it has to do.

§ IV. — Of inclination and conicity.

55. Conicity of the tires, as well as its immediate consequence inclination of the rails date almost from the commencement of railways; but their utility has lately been called into question, and even formally disputed: it is a point of too much interest to be passed over without a few remarks.

It must be fully understood, that we are not referring to the circulation in curves, for under this condition, the advantages of conicity are too great to be denied; an attempt has been made to retain it in sharp curves, while discarding it in straights and in curves of considerable radius: here however we shall only advert to it in connexion with straights. Its object is, within certain limits, to counteract the many causes, which tend to make the axles assume an oblique position, relatively to the line; and to keep one, or other of the flanges of the two wheels on the same axle, pressed against the edge of the rail. The existence of this influence in this direction can hardly be doubted, even apart from actual experience; at the same time, however, its inconveniences cannot be denied, at least in principle; for the utility of its effects

results from the inequality in the radii of rotation of the two wheels on the same axle; necessarily entailing oscillations of the axle to either side of its mean position, which is horizontal, and at right angles to the line; and which oscillations are increased, as regards the carriages, by the play of the springs.

It is precisely for this reason, that the conicity, and, as a consequence, the inclination of the rail, when straights only are considered, ought not to exceed a certain limit, up to which they are advantageous, but beyond it become injurious; it is merely a question of amount.

50. On the line between Paris and Sceaux, there is neither conicity, nor inclination in the rail; this is however, but a natural consequence of the wheels being left free, one of the features of the articulated rolling-stock of the late Mr Arnoux.

It was thought, that Mr McConnell's system of rails on metallic supports, could be laid without any inclination; this was tried on the Bristol and Exeter line, and is described farther on: the necessity of repairing the mistake was however afterwards seen: it is true, that the rolling-stock employed on these rails, without inclination, had conical tires: here the inclination was slightly less than the conicity; $\frac{1}{24}$ in place of $\frac{1}{20}$, the figure adopted on the principal lines in England, as well as in France.

The engineers of one of the last constructed important lines in Austria, viz. the Western, from Vienna to Salzburg, were convinced, that conicity was unnecessary; this once admitted, it was easy to indict and condemn it as decidedly injurious; were it only in consideration of the convexity of the rail, which was considered unfavourable to the distribution of the pressure between the wheels and the rails, and moreover a consequence of the conicity only.

This method of considering the matter may in itself be much disputed; in theory, no doubt, with cylindrical tires, the rolling surface of the head of the rail might, and indeed should, be flat and broad; but if the inevitable alterations in the shape of the tire, and the slight displacements from the perpendicular, to which the rail is liable, be taken into consideration, it will be understood, that this broad rolling surface, good no doubt for a theoretical idea of perfection, or for a mere passing state of things, must in reality be very bad; and especially so, in regard to the distribution of pressure. In attempting to increase the breadth of the zone of contact, the contrary effect is produced, or even worse still, the load is thrown upon that portion of the rail least able to bear it; namely, on the edge of the head, and more particularly on the outside edge. These effects are not dependent upon the conicity; either with, or without it, they ought to be counteracted; now the only method is to be certain, despite

all errors of plate-laying, or alteration of form, that the zone of contact is always the centre of the head of the rail, directly over the web; and this is effected by giving a sufficient convexity to the head. Convexity, as defined above, appears therefore to be as necessary with the vertical rail and the cylindrical tire, as with the inclined rail and the conical one.

As the opinion contrary to conicity alone prevailed on the Western of Austria line, the vertical rail was adopted, convex at top however, with conical tires, or rather cylindro-conical, as will be shown hereafter; the result however has far from corresponded with the expectations of the originators. The wheels instead of oscillating round their mean position, that state of equilibrium to which conicity always tends to bring them, pressed with perfect impunity their flanges against the rails, or at least without any other obstacle than transverse friction; the sleepers became unpacked and the permanent way got out of order; in a word, the amount of repairs, as well as the wear and tear, far from being diminished, were greatly increased. In curves, which were passed over in one direction only, the sleepers became skew with the axis of the line; attempts were made to counteract this defect, where there was a double way, by causing the trains to change lines at stated intervals; so that they might run sometimes in one direction, and sometimes in the other. In fact, it was at length found necessary to restore, to the ordinary conditions, the permanent way and the rolling stock on the Western of Austria. Such is the result of this experiment, interesting in itself, but the more so, from its having eventually confirmed the correctness of the views of our first railway engineers, and from having henceforth placed entirely out of doubt the necessity of a certain inclination in the rail.

57. Conicity was also discarded on the Indian Branch Railway, already referred to; this line is remarkable for many ingenious arrangements, to be described farther on; for the details of which we are indebted to the kindness of Mr E. Wilson, engineer in chief of the line. The rail, inverted ⊤, has a head $2\frac{1}{2}''$ broad; it is perfectly flat on the top for $1\frac{7}{8}''$, with the edges rounded off, and has straight vertical sides (Pl. IX, fig. 1, 2, 3). The disadvantages complained of in Austria have not yet been felt on the Indian line; where however the speed is slow, not exceeding 25 miles per hour. Hence we might infer, that the effect produced by the suppression of conicity is but small; and that it is essentially a question of speed.

58. The question of conicity has been frequently discussed by the German engineers at their annual meetings : on these occasions however, the principle

has never been questioned, but the majority have come to the conclusion, that in certain instances its limit has been exceeded, while in others the contrary has been the case; in 1859 at the Trieste meeting 1 in 20 was adopted as the minimum inclination; below which ratio it had never previously been reduced in Germany. Some observations have since induced certain engineers to regard this as too low a figure; and as one with which the gauge would have more tendency to widen out, than with a greater inclination; as an example of the contrary, the inclination of 1 in 16, which is adopted on several lines, among others on the Cologne and Minden, has been considered too great. In fact 1 in 17 seems to offer the greatest resistance to alteration, and on this account deserves the preference for main lines. The meeting of 1865, which does not appear to have discussed the question, contented itself with reiterating the recommendation of 1859, and indicated 1 in 20, as the minimum limit (*).

This however has not been universally agreed to; thus the inclination, on the mountain-railway of Silesia, has been reduced to 1 in 24; and is done away with altogether in stations, and at points and crossings on the line.

The smallness of the inclination was, in this case, a necessary consequence of the form of the rail; with such a broad rolling surface (57), an increased inclination, necessarily combined with a greater conicity, would have added to the slipping of the tires. A slight inclination was also still more necessary with that of Mr Daelen (52); where 1 in 24 was also adopted. When considering the question, this dependance upon one another of the various elements of the permanent way is constantly manifest; thus causing each to be judged of, and determined upon relatively with the rest.

§ V. — Methods of fastening the rails to the sleepers.

59. The chair is fixed to the sleepers by means of iron spikes, or screws (Western of France), inserted in the bottom of it. The foot of the Vignoles rail, might be fixed exactly in the same manner; it has even been done so sometimes, either at all the sleepers or only at the joints; as on the London Chatham and Dover, and on the Belgian Luxemburg (Pl. IV, fig. 21).

By applying the fastenings however outside the foot, there is the triple advantage of doing away with the holes; of affording its maximum leverage to the longitudinal resistance, in the event of its being called into action by a tendency to turn over; and lastly of maintaining a complete liberty,

(*) "Technische Vereinbarungen", 1866, etc., art. 15.

as to the arrangement of the sleepers : one notch, at least, ought to be made at each side, in the edge of the foot to prevent the longitudinal displacement of the rail (105).

The essential duty of the fastenings is to counteract the transverse slipping of the rail; but they must also, as we have seen (39), keep the foot closely pressed against the sleeper, and thus prevent any up and down motion, which destroys the timber; they must therefore be furnished with a projecting head, and be very solid.

Spikes or screws are generally used; at present they are pretty generally galvanised, especially when the sleepers are prepared with sulphate of copper. Wooden pegs even when compressed, sometimes solid, sometimes hollow with an iron core, and which were long in use in England to fasten down chairs, are wanting in solidity, although the precaution was often taken to fix two on the outside; the Board of Trade, recommended that they should be no longer used on English lines. In France the line from Montereau to Troyes, which adopted them, was soon obliged to discontinue them, notwithstanding the easy nature of the line, and the lightness of the engines in use on it up to the time, when it became almost entirely comprised in the main line from Paris to Mulhousen.

The spikes are always smooth, not notched, and are often sloped off at the bottom, when the sleeper is not pierced quite through, at right angles to the lateral faces of the head; this form is less liable, than any other to split the wood, because the workman is compelled to place the edge across the fibre; an arrangement, which is often avoided with fastenings, having circular heads; as for instance, the chair pegs on the Orleans line, which have a sort of chisel at the bottom; a small notch made in the head pointing out the direction of the edge, it need not determine its absolute position, but enables it to be controled.

The body of the spike is sometimes an inverted pyramid, with the faces slightly inclined, of a swallow-tail shape (for example the Western of Switzerland, Pl. V, fig. 36); this form however has been generally discarded, though trials made in Hanover have demonstrated, as might have been expected, that it augments the resistance to removal. But as it has already sufficient of the prism form, it is better to give a little of the conical shape to the spike, in order to reduce its resistance to longitudinal strain, without diminishing that to transverse : it is only on a badly laid line, that resistance to extraction can be seriously called into play; if a poorly packed sleeper gives way under the load, the rail bends considerably, and on resuming its original position it drags back the sleeper sharply, which resists by its inertia and by its own weight; if this effect often takes place, the spikes, or the screws,

soon become loose; but on a well ballasted, and well kept line, this can only occur accidentally, or after long continued frost.

The interior faces of the head and the body, united by a rounded edge, form an angle more or less obtuse, to enable the head to fit closely down on the foot, if the axis of the spike has been correctly driven, perpendicularly to the foot of the rail; that is to say with an inclination of 1 in 16, or 1 in 24, from the vertical (55 to 58).

Sometimes however the angle in question being a right angle, the spikes are driven obliquely and converge; this arrangement is bad, as regards resistance either to slipping, or to the overturning of the rail; in the first case it tries the tension of the spike, and increases it in the second; it is besides more difficult of execution. Insufficiency of inclination in the spike is especially a grave defect; for it is principally by its grip near the shank, and not by the edge of the head, that the spike ought to rest on the foot of the rail, otherwise it is liable to break.

Spikes with symmetrical polygonal heads, twisted into screws with a coarse, shallow thread are often used; they are inserted by hammering like the ordinary spikes, no holes being previously bored; in Hanover however it is forbidden to drive them during any great heat, on account of the tendency of the sleepers to split: the screws were inserted upright, their broad head and body being united by a shoulder, shaped to fit exactly the foot of the rail. These screws have the advantage of being more easily extracted, than spikes; they can be unscrewed by turning, the same as if they had been inserted in this manner. But experience has not proved favourable to this cross between the spike, and the proper wood screw. The fact of hammering in a screw must disturb the fibres of the timber; and it ought to turn, while penetrating the wood under the action of the blows. I have often been assured, that this is the case; but I have however often observed the contrary in Bavaria, and in Prussia, where this plan is much in vogue. Rotation might perhaps result, if the driving were conducted with greater care.

60. At present the only methods in use are the spike, driven in by hammering, and the screw, inserted by means of a key, in a auger hole, of somewhat less diameter than the body of the screw (61); except at the joints, where bolts are frequently used (64, 85). For a long time engineers invariably preferred spikes for oak sleepers, and screws in other cases; now however the screw is often used even with oak sleepers. The Northern, and the Eastern of France lines, for example, use it exclusively at the present time, after having previously tried the spike (Pl. V, fig. 14, 15). It is seldom, that the screw is abandoned for the spike; such is, however, the case with the in-

verted ⊤ rail, in use on the Belgian State Railway, and on the Semering line.

In soft wood the spike is easily loosened; in hard on the contrary, it often becomes difficult of extraction (59); were this the only objection, the length and size of the spike might be decreased, but the resistance to the horizontal strain would be thereby reduced at the same time; and in this it often fails, especially in curves. Another complaint against spikes, much less serious in itself, and which is often exaggerated, is the tendency of the head to break off. As has been already observed (39); it is indispensable, that the head should rest on the foot of the rail, to keep it in contact with the sleeper. In driving them, when the two are almost in contact, too strong a blow may knock off the head; and if the plate-layer, aware of this risk stops too soon, the connexion of the rail with the sleeper is imperfect, a slight up and down motion results, and rapidly increases in amount.

With the screw, contact is effected with certainty, and without difficulty, but its great advantage over the spike is its facility of extraction; it is also manifest, that the custom, of driving screws with the hammer, ought to be strictly forbidden. On the Northern of France line, disobedience on this point has been prevented, by having, on the head of the screw, a small projecting point; which, if defaced, is a sure tell-tale of the careless workman (Pl. V, fig. 14). On the Eastern of France line the same result is obtained by a raised letter, E, which protects the head (fig. 15).

61. *Resistance to extraction.*

On the last named line several experiments have been made, in relation to the resistance of spikes and screws: in them, resistance to extraction was made the test, while on the contrary it is resistance to transverse strain, that it is most important to ascertain; as there is nothing, which authorizes us, from the amount of the former resistance, to deduce that of the latter. It is interesting, however, to learn the results of these experiments, which have been kindly furnished to me by M[r] Ledru, engineer in chief of the Eastern of France line.

" Every spike, or screw, experimented on, was inserted once, and then subjected to " the action of a pulling force by means of a lever, loaded at one end; by this means " were obtained the results in column I. In this first experience the spike, or screw, " was drawn $\frac{1}{8}''$ out of the hole, a stop checking the movement of the lever; it was " then driven in a second time, and the experiment repeated; this gave the results " shown in column 2; and so on. In oak sleepers, at the moment of reaching the ex- " treme strain, the fastenings give very slowly, in prepared beech, the same result " takes place but only up to a height of from $\frac{1}{16}''$ to $\frac{1}{12}''$, but the latter part of the move- " ment is much accelerated: with prepared fir, on the contrary, the motion of the " fastening, up to $\frac{1}{8}''$, continues during the whole time with considerable rapidity, even

" quickening towards the end : with prepared hornbeam the screws give from $\frac{1}{25}''$ to $\frac{1}{16}''$ under the weights, shown in the column of remarks; then they remain stationary, and a much greater weight must be applied to raise them completely out; this movement takes place more slowly, than in the case of oak.

" In columns from 2 to 6, it may be observed, that the numbers do not decrease in regular proportion; this arises from the screwing in of the fastenings, which it was difficult to effect always in a regular way.

" The diameter of the holes first bored, does not, within certain limits, materially influence the resistance of the fastenings; it is only in the length inserted into the wood, that any considerable differences are seen; it may, however, be remarked, that in the results obtained with screws for the Vignoles rail, the one with the amount of twist used on the Western of France, and driven into a hole $\frac{5}{8}''$ in diameter affords in general the greatest resistance to extraction.

" The trials made with a birch sleeper afforded unsatisfactory results; in the table it is shown, that screws of various shapes are always in this case, inferior in resistance to extraction with the highest weights, to those inserted in oak, beech, and hornbeam, by at least $1\frac{1}{2}$ tons.

" Birch, although compressed, has no elasticity, nor tenacity. When holes are bored in it, it does not grip the auger, which requires to be constantly pressed down, in order to make it work; the shavings are ground to powder; likewise, when the screws are inserted for the third time, they can be turned round and round without any effort; this wood does not therefore give good results with an inverted ⊤ rail; and, though perhaps a little superior, still it must be classed with fir and other soft woods. "

Table of experiments of the extraction of screws and of spikes from sleepers made of different sorts of timber.

SPECIES of wood.	KIND OF SCREW, OR SPIKE.	Diameter of hole.	Length inserted.	FORCE PRODUCING EXTRACTION. N° 1.	N° 2.	N° 3.	N° 4.	N° 5.	N° 6.	REMARKS.
		inch.	ins.	tons. cwt.	tons. cwt.	tons. cwt.	tons. cwt.	tons. cwt.	tons. cwt.	
Oak.	Screw for Vignoles rail, Eastern of France, 5 7/8" long, by 3/4" in diameter.	5/8	3 3/8	3 13	2 4 3/4	1 6 1/4	1 2 3/4	»	»	The weight of the lever and scale was one ton. The forces marked in the columns 1 to 6 are the product of the weight placed in the scale; multiplied by 40; the above weight of 1 ton is then added; and 1/10 subtracted from the sum for friction.
	Id. *id.*	9/16	3 3/8	3 19 1/2	3 1 3/4	1 15 1/2	1 9	»	»	
	Screw for Vignoles rail, Western of France, 5 5/16", by 3/4".	9/16	3 3/8	4 0	3 3 3/4	1 19 3/4	1 8 1/4	»	»	
	Id. *id.*	1/2	3 3/8	3 17 1/4	2 18	1 14 3/4	1 9 3/4	»	»	
	Screw for Vignoles rail, Western of France, 5 11/16", by 3/4".	5/8	3 3/8	3 15 3/4	2 11	1 12 1/2	1 3 1/2	»	»	
	Id. *id.*	9/16	3 3/8	3 17 1/4	3 1 3/4	2 2 1/2	1 9 3/4	»	»	
	Id. *id.*	1/2	3 3/8	3 15 3/4	3 3	2 6 3/4	1 11 1/4	»	»	
	Screw for chairs, Eastern of France, 5 7/8", by 3/4".	5/8	3 15/16	4 17	3 8	2 10 1/4	1 10 1/2	»	»	
	Id. *id.*	9/16	3 15/16	4 3	2 19 1/2	1 19 3/4	1 9	»	»	
	Screw for chairs, Western of France, 5 1/2", by 3/4".	9/16	3 15/16	5 2	3 17 1/4	2 14 1/2	1 15 1/2	1 6 1/4	»	
	Id. *id.*	1/2	3 15/16	4 7	3 5 1/4	2 4 3/4	1 9 3/4	1 2	»	
	Screw for Vignoles rail, thread very slight.	5/8	3 3/8	3 8 3/4	2 17 1/2	2 12 1/2	2 9 1/2	2 6 3/4	2 6	
	Spike with chamfered edges of the Lyons railway.	5/8	4 5/16	4 2 1/4	3 11 1/2	3 3 3/4	3 2 1/4	3 1	2 18	
	Pointed screw for Vignoles rail, new form.	5/8	4 1/8	4 10	3 16 1/2	2 16	1 14	»	»	
Prepared beech.	Screw for Vignoles rail, Eastern of France.	5/8	3 3/8	3 15	2 9 1/2	1 12 1/2	1 4 3/4	»	»	
	Id. *id.*	9/16	3 3/8	3 17 1/4	2 12 1/2	1 15 1/2	1 6 1/4	»	»	
	Screw for Vignoles rail, Western of France.	9/16	3 3/8	4 0 3/4	2 15 1/4	2 4	1 7	»	»	

Continuation of the preceding Table.

SPECIES of wood.	KIND OF SCREW, OR SPIKE.	Diameter of hole.	Length inserted.	FORCE PRODUCING EXTRACTION. N° 1.	N° 2.	N° 3.	N° 4.	N° 5.	N° 6.	REMARKS.
		inch.	ins.	tons. cwt.	tons. cwt.	tons. cwt.	tons. cwt.	tons. cwt.	tons. cwt.	
Prepared beech (*continued*).	Screw for Vignoles rail, Western of France.	1/2	3 3/8	4 0	2 18 3/4	1 14 3/4	1 6 1/4	»	»	
	Screw for Vignoles rail, Eastern of France, 9/16″ in diameter	5/8	3 3/8	3 17 1/4	2 18 3/4	1 19 3/4	1 2 3/4	»	»	
	Id. *id.*	9/16	3 3/8	3 18	3 1	1 17 1/2	1 2	»	»	
	Id. *id.*	1/2	3 3/8	3 13	2 19 1/2	2 0 1/2	1 4 3/4	»	»	
	Screw for chairs, Eastern of France.	5/8	3 15/16	4 7 3/4	3 3 3/4	1 19 3/4	1 9 3/4	»	»	
	Id. *id.*	9/16	3 15/16	4 5	3 2 1/4	2 1	1 11 1/4	»	»	
	Screw for chairs, Western of France.	9/16	3 15/16	5 0 3/4	3 18	3 16 3/4	2 6	2 5 1/4	»	
	Id. *id.*	1/2	3 15/16	5 2	3 19 1/2	2 5 1/4	1 14 3/4	1 5 1/2	»	
	Screw for Vignoles rail, thread very slight.	5/8	3 3/8	3 12 1/4	2 14 1/2	2 11 3/4	2 9 1/2	2 7 1/2	2 5 1/4	
	Spike of the Lyons railway pattern.	5/8	4 5/16	4 10	4 0 3/4	3 10 3/4	3 10 3/4	3 3 1/2	3 3 1/2	
	Screw for Vignoles rail, Northern of France.	9/16	3 3/8	3 15	2 10 1/4	1 4	»	»	»	
	Id. *id.*	1/2	3 3/8	4 1 1/2	2 18 3/4	1 18 1/4	1 1 1/4	»	»	
	Round peg, Eastern of France.	5/8	4 15/16	4 15 3/4	4 1 1/2	3 13	3 13	3 10 3/4	3 7 1/4	
	Spike, Eastern of France	5/8	»	2 12 1/2	2 9 1/2	2 4	2 2 1/2	2 2 1/2	2 0 1/2	
Prepared hornbeam.	Screw for Vignoles rail, Eastern of France.	5/8	3 3/8	4 10	3 4 3/4	2 2 1/2	1 9	»	»	Extracted between 3 tons and 3 tons 8 cwt.
	Id. *id.*	9/16	3 3/8	4 10 3/4	3 3 3/4	2 4 3/4	1 9 3/4	»	»	
	Screw for Vignoles rail, Western of France.	9/16	3 3/8	4 12	3 13	2 18 3/4	1 15 1/2	1 4 3/4	»	Between 3 tons 8 cwt and 3 tons 14 cwt.
	Id. *id.*	1/2	3 3/8	4 11 1/2	3 9	2 16 3/4	1 13 1/4	1 6 1/4	»	

Continuation of the preceding Table.

Species of wood.	Kind of screw, or spike.	Diameter of hole.	Length inserted.	Force producing extraction. N° 1.	N° 2.	N° 3.	N° 4.	N° 5.	N° 6.	Remarks.
		inch.	ins.	tons. cwt.	tons. cwt.	tons. cwt.	tons. cwt.	tons. cwt.	tons. cwt.	
Prepared hornbeam (*continued*).	Screw for Vignoles rail, Western of France, 9/16" diameter.	5/8	3 3/6	3 19 1/2	3 8 3/4	1 13 1/4	1 9 3/4	»	»	Between 3 tons and 3 tons 5 cwt.
	Id. *id.*	9/16	3 3/8	4 5 3/4	3 13 3/4	2 9 1/2	1 14	1 5 1/2	»	
	Id. *id.*	1/2	3 3/8	4 5	3 3 3/4	2 6 3/4	1 10 1/2	»	»	
	Screw for chairs, Eastern of France.	5/8	3 15/16	5 13 1/2	3 9 1/2	2 4 3/4	2 0 1/2	1 17 1/2	»	Between 4 tons 5 cwt and 4 tons 8 1/2 cwt.
	Id. *id.*	9/16	3 15/16	5 6 1/4	3 8	2 2 1/2	1 14	1 9	»	
	Screw for chairs, Western of France.	9/16	3 15/16	5 12 1/4	3 10 1/4	2 1	1 15 1/2	1 9 3/4	»	
	Id. *id.*	1/2	3 15/16	4 19 1/4	4 5	2 7 1/2	1 18 1/4	1 11 1/4	»	
	Screw for Vignoles rail, thread very slight.	5/8	3 3/6	2 9	2 5 1/4	2 5 1/4	2 4	2 3 1/4	2 2 1/2	
	Spike of the Lyons railway pattern.	5/8	4 5/16	3 6	3 1	3 0 1/4	2 18 3/4	2 18 3/4	2 18	
Prepared fir.	Screw for Vignoles rail, Eastern of France.	5/8	3 3/8	2 1 3/4	1 4	12 1/2	»	»	»	
	Id. *id.*	9/16	3 3/8	2 4 3/4	1 7	13 3/4	»	»	»	
	Id. *id.*	1/2	3 3/6	1 15 1/2	1 2 3/4	11	»	»	»	
	Screw for Vignoles rail, Western of France.	9/16	3 3/8	2 11 3/4	1 14	17 3/4	»	»	»	
	Id. *id.*	1/2	3 3/8	2 6 3/4	1 11 1/4	17 1/4	»	»	»	
	Screw for Vignoles rail, Western of France, 9/16" diameter.	5/8	3 3/8	2 6	1 7 1/2	17 3/4	»	»	»	
	Id. *id.*	9/16	3 8/6	2 9	1 11 1/4	17 1/4	»	»	»	
	Id. *id.*	1/2	3 3/8	2 6	1 10 1/2	15 1/4	»	»	»	
	Screw for chairs, Eastern of France.	5/8	3 15/16	2 13 3/4	1 12	19 3/4	»	»	»	
	Id. *id.*	9/16	3 15/16	2 16 3/4	1 13 1/4	15 1/4	»	»	»	
	Id. *id.*	1/2	3 15/16	2 2 1/2	1 9 3/4	13 3/4	»	»	»	

Continuation of the preceding Table.

SPECIES of wood.	KIND OF SCREW, OR SPIKE.	Diameter of hole.	Length inserted.	FORCE PRODUCING EXTRACTION. N° 1.	N° 2.	N° 3.	N° 4.	N° 5.	N° 6.	REMARKS.
		inch.	ins.	tons. cwt.	tons. cwt.	tons. cwt.	tons. cwt.	tons. cwt.	tons. cwt.	
Prepared fir (*continued*).	Screw for chairs, Western of France. . . .	$\frac{9}{16}$	$3\frac{15}{16}$	2 $19\frac{1}{2}$	1 $16\frac{1}{4}$	1 $1\frac{1}{4}$	»	»	»	
	Id. *id.*	$\frac{1}{2}$	$3\frac{15}{16}$	2 $14\frac{1}{2}$	2 $0\frac{1}{2}$	1 $1\frac{1}{4}$	»	»	»	
	Screw for Vignoles rail, thread very slight.	$\frac{5}{8}$	$3\frac{3}{8}$	1 $5\frac{1}{2}$	$19\frac{1}{4}$	$18\frac{1}{2}$	$16\frac{3}{4}$	$16\frac{3}{4}$	$16\frac{3}{4}$	
	Id. *id.*	$\frac{1}{2}$	$3\frac{3}{8}$	1 7	$19\frac{3}{4}$	16	16	16	16	
	Spike of the Lyons railway pattern.	$\frac{5}{8}$	$4\frac{5}{16}$	2 $0\frac{1}{2}$	1 $14\frac{3}{4}$	1 $11\frac{1}{4}$	1 $9\frac{3}{4}$	1 $9\frac{3}{4}$	1 9	
	Id. *id.*	$\frac{9}{16}$	$4\frac{5}{16}$	2 $2\frac{1}{2}$	1 $15\frac{1}{2}$	1 $12\frac{1}{2}$	1 $11\frac{1}{4}$	1 $11\frac{1}{4}$	1 $10\frac{1}{2}$	
	Spike, Eastern of France.	$\frac{1}{2}$	$4\frac{3}{4}$	1 $9\frac{3}{4}$	2 1	1 $7\frac{1}{2}$	1 $6\frac{1}{4}$	1 $5\frac{1}{2}$	1 $5\frac{1}{2}$	
Birch. . .	Screw for Vignoles rail, Eastern of France.	$\frac{5}{8}$	$3\frac{3}{8}$	2 $7\frac{1}{2}$	1 $12\frac{1}{2}$	$19\frac{3}{4}$	»	»	»	
	Id. *id.*	$\frac{9}{16}$	$3\frac{3}{8}$	2 11	1 $15\frac{1}{2}$	1 $1\frac{1}{4}$	»	»	»	
	Screw for Vignoles rail, Western of France.	$\frac{9}{16}$	$3\frac{3}{8}$	2 $13\frac{3}{4}$	1 $16\frac{3}{4}$	1 $0\frac{1}{2}$	»	»	»	
	Id. *id.*	$\frac{1}{2}$	$3\frac{3}{8}$	2 $15\frac{1}{4}$	1 19	1 2	»	»	»	
	Screw for Vignoles rail, Western of France, $\frac{9}{16}$" diameter.	$\frac{5}{8}$	$3\frac{3}{8}$	2 $12\frac{1}{2}$	2 $0\frac{1}{2}$	1 $2\frac{3}{4}$	»	»	»	
	id. *id.*	$\frac{9}{16}$	$3\frac{3}{8}$	2 9	1 $17\frac{1}{2}$	1 $0\frac{1}{2}$	»	»	»	
	Id. *id.*	$\frac{1}{2}$	$3\frac{3}{8}$	2 $10\frac{1}{4}$	1 $19\frac{3}{4}$	1 $3\frac{1}{2}$	»	»	»	
	Screw for chairs, Eastern of France.	$\frac{5}{8}$	$3\frac{15}{16}$	3 $3\frac{3}{4}$	2 $5\frac{1}{4}$	1 $8\frac{1}{4}$	»	»	»	
	Id. *id.*	$\frac{9}{16}$	$3\frac{15}{16}$	3 3	2 6	1 $9\frac{3}{4}$	»	»	»	
	Screw for chairs, Western of France. . . .	$\frac{9}{16}$	$3\frac{15}{16}$	3 $5\frac{1}{4}$	2 $7\frac{1}{2}$	1 9	»	»	»	
	Id. *id.*	$\frac{1}{2}$	$3\frac{15}{16}$	3 6	2 $10\frac{1}{4}$	1 12	»	»	»	
	Screw for Vignoles rail, thread very slight.	$\frac{5}{8}$	$3\frac{3}{8}$	1 12	2 $10\frac{3}{4}$	1 $6\frac{1}{4}$	1 $5\frac{1}{2}$	1 $4\frac{3}{4}$	»	
	Spike of the Lyons railway pattern.	$\frac{5}{8}$	$4\frac{5}{16}$	2 $5\frac{1}{4}$	2 $0\frac{1}{2}$	1 $18\frac{1}{4}$	1 $16\frac{3}{4}$	1 $16\frac{1}{4}$	»	

It results from these experiments, that the resistance of the spike, or of the screw with but little thread, is diminished much less by successive extractions, than that of the screw proper. The former has often lost less at a fifth, and even at a sixth extraction, than the screw has at a third. This is however of little importance in the case which we are now considering, nor is it more, than might be expected; for when the screw is once withdrawn, it necessarily leaves the fibres of the wood disorganised, and the hole enlarged; while the friction, which constitutes the resistance of the spike, alters but little.

In the first withdrawal the screw does not appear to have any considerable advantage, over the spike in oak, and in beech; *i. e.* in hard woods; but it is sufficiently marked in fir, and especially in birch and in hornbeam.

67. If there is any real tendency in the rail to overturn, it should have induced engineers, who assert it, to adopt, with the softer kinds of wood, the screw for the interior of the line, even when the spike seems to them preferable for the exterior; as, with the hypothesis, that the two fastenings are subject to quite distinct strains, in the one case especially to longitudinal ones, and in the other to transverse, it would be only natural, that their respective natures should be in keeping with these different conditions. Now, admitting, which is by no means demonstrated, that screws become loosened more rapidly than spikes under the action of transverse strain, it can hardly be contested, that the former with soft wood are more fit to resist a first extraction. It is however, unless sometimes at the joints, the same mode which is always applied, both inside and out, without distinction, on sharp curves, and on straights; it would therefore have been very easy to have sought to augment the resistance to extraction, had it been really called into play; which proves indirectly, that the alleged tendency to overturning is by no means founded on observation.

68. *Tendency of the fastenings at the joints to be drawn, where fish-plates are not used.*

There are undoubtedly certain points where the tendency to extraction of the fastenings, whether screws or spikes, is manifest; such as at the extremities of rails, which are not fished; but this tendency affects them alike on the outside, and on the inside. It results, in fact, not from the tendency of the rail to overturn, but from the transverse vibrations, and from the vertical up and down movement of the end of the rail, which, as soon as it has caused the fastenings to become loose, rapidly destroys the joint sleeper, by the fact that the condition of contact is no longer fulfilled at the very point, where of all others it is the most indispensable.

With the inverted T rail, then, the necessity was speedily recognised, 1st to make the fastenings at the joint stronger than elsewhere; 2nd to protect the wood against the vibrations of the ends of the rails, by a sort of metal shield.

This was at best but applying a remedy to certain inconveniences, instead of seeking, as is now generally done, and with almost complete success, to do away with the cause itself; viz, want of continuity in the rails.

The use of fish-plates places the end fastenings on the same conditions, as the intermediate ones; rendering these indirect remedies, of little, if any use.

They are however still often employed in Germany, in conjunction with fish-plates.

84. The addition most in use consists of a plate of iron, which fulfils the triple function, of protecting the sleepers, of connecting together the four fastenings, and of holding, between two lateral raised edges, the foot of each of the two adjoining rails; thus causing their upper members to coincide, much less imperfectly.

The first bed plates, mostly of cast iron, had two triangular projections, fitting into notches in the foot at the ends of the rails, to prevent the longitudinal displacement (105); these were subsequently done away with.

Upon some lines, the Semering among the rest, the plates give the inclination to the rails; an intermediate one, but not so broad, is also used on this line, it is especially intended for curves; and perhaps also to furnish an additional guide for the inclination, and to afford greater precision in laying the rails.

On some portions of the Bavarian Railways, from Kempten to Lindau, and from Bamberg to Aschaffenburg, the joint plate was replaced by two cast iron plates, independent of each other, being in fact rough chairs, placed side by side upon the joint sleeper; the rail is held down, on the inside, by a small lap of the chair itself, and upon the outside by the large head of the spike: this arrangement, in conjunction with fish-plates is a complication, which the latter renders perfectly useless.

Plates, spikes, and screws were all used together in relaying the permanent way of the Baden Railways, when the gauge was reduced from 5'.3" to the ordinary one; a plate, four spikes, and four pegs, twisted into the form of screws were used at each joint. It is difficult to understand, why spikes and screws were both used, under exactly similar conditions; and also why the latter should have been inserted in an eye pierced in the foot, instead of being placed outside, against the edge.

Upon the line from Stargard to Colberg, opened in 1859, the rails, of the form called the "Ministerial" of Prussia, are supported at the joint upon a plate with raised edges exactly fitting the foot; there are on the outside two spikes, and on the inside two bolts, inserted through the plate, and resting upon the foot, the former with their heads, the latter with their nuts; the bolt heads, cross-bar shape, fit into a groove upon the lower face of the sleeper; and thus resist rotation, whilst the nuts are being tightened (Pl. VI, fig. 19 and 20).

65. On some lines, they went so far, as to place in fact a complete chair at the joints of an inverted ⊤ rail, but which was necessarily very broad, and with a wooden wedge. This unfortunate combination of two opposite systems, each properly excluding the use of the other, was applied by way of experiment upon the Railways, from Brunswick to Luneburg, of Electoral Hesse, and of Saarbrücke; upon the Maine-Weser line this complication was even increased, by the addition to the chair, in the curves of very small radius, of a sort of iron protecting plates, connecting the outer edge of the rail with the inner one of the chair; designed to act in place of the wedge, in case of its falling out, and indirectly to relieve the exterior jaw of the chair.

66. On the Saarbrücke line, it was proposed, as had already been done upon a section of the line from Stargard to Posen, in order to avoid the consequences of the loosening, and falling out of the ordinary wedge, to substitute for it a double wedge, composed of two parts united by a bolt; and thus forming a species of swallow tail (Pl. VI, fig. 0 and 31).

Experience was happily not long in giving to all these complications their proper desert, and in arresting engineers in the false direction in which they were proceeding.

The screws and spikes, as well as the bolts, much less used in general, pass through the joint plate, and are placed in twos, as in the case of intermediate sleepers, in an oblique direction to the rail, to avoid splitting the sleeper.

Although the springing movement at the joint (37) was already less marked, with the inverted ⊤ rail with joint plates and bolts, than with the chair-rail keyed up with wedges, the necessity has long been recognized of insuring a more exact coincidence of the ends of the rails. On the Berlin and Stettin Railways, the plate was doubled over the outside edge of the foot, on the upper side of which rested the heads of the spikes: this lap in the plate was, after a time, replaced by a sort of flat bar turned back, and fastened upon the foot by bolts with the nuts above, themselves acting as spikes; these sort of hori-

zontal fish-plates were then placed at the two sides; sometimes they were made very short, fixed by a single bolt placed exactly at the joint; at other times longer, with two, or even three, bolts on each side.

These modifications already constituted some real progress; it is however useless to describe them in detail, but merely to mention them, to show how complete and varied have been the attempts, while adapting the Vignoles rail to general use; and what a lengthened series of experiments it has required to arrive at the much more practical arrangements, in use at the present time.

A species of flat saddle-plate has sometimes been combined with the fish-plate, for example upon the line from Berlin to Frankfort (Pl. IV, fig. 4 and 5), on that from Grenoble to Saint-Rambert (Pl. V, fig. 5), and quite recently upon the "Gebirgs Bahn" of Silesia (Pl. V, fig. 28, 29).

67. The shorter length of the span at the ends of the rails compensates, and often does more than this, for the disadvantages of its position, in respect to transverse resistance; but it still leaves the inconveniences, which arise from the independence of the consecutive rails; viz, considerable deflection under the load, springing action of the joints, vibrations, and up and down movement of the ends, when loose; all of which are merely lessened. The only really effective means of getting rid of them, lies in complete connection between the rails, and so to transform them into a continuous line, allowing its elements only sufficient freedom, in a longitudinal direction, to provide for the alterations of temperature.

Were it not for this last condition, a joint-plate bolted under the foot of an inverted ⊤ rail would be a very satisfactory means of effecting this continuity; it would act as a cover-joint, placed in the most favourable manner for re establishing transverse resistance; a point equally essential, whether the joint be supported, or not (74); indeed in this respect it might be preferable even to fish-plates.

This arrangement was tried upon the Eastern of Prussia Railway; it afforded good joints, possessing considerable resistance, provided the rails were well butted together: in an experiment made by means of the lever-press (19), fracture took place under a load of 13 $\frac{1}{2}$ tons, about half of that under which a continuous rail was broken.

But, as it is necessary to leave, at least here and there some space to afford play for the rails (124), and likewise to make the bolt holes oval, the plate then ceases to fulfil the office of a real cover-joint, and the arrangement loses much of its resistance, if the tops of the heads are not exactly level with each other.

Fish-plates are much more simple; and they ensure much more exactly a perfect level between the edges of the heads, which is the essential point.

CHAPTER III.

ESTABLISHMENT OF CONTINUITY AT THE JOINTS, BY MEANS OF FISH-PLATES; STRAINS ON THE METAL IN THE RAILS, FISH-PLATES, AND BOLTS.

§ I. — Determination of the section of rupture, and of the molecular strains of the rail, in intermediate spans, and at the end ones, with or without fish-plates.

68. The rails by their general form are well suited to be joined at their ends, by means of lateral plates; and which, lodged in the hollow on either side of it, deflect simultaneously with it, by virtue of the strains distributed throughout their whole length, though very unequally, by the upper and lower members. The end of the rail submitted to the load carries with it, in its deflection, the rail joined to it by means of the fish-plates, even before this latter is reached by the wheel; and thus prepares it to receive in its turn the load, without any violent shock taking place.

Such is the principle of the fish-plate: its use, now almost general wherever the form of the rail is suitable, dates sometime back; it was applied for the first time in Europe in 1847, upon the line from Dusseldorf to Elberfeld, and even previously to this, as it appears, in the United States.

Whatever may be the details adopted for forming the joints of the rails, it is there, that always, in a system thus rendered continuous, occurs the section of least resistance: the position of the joint, relatively to the supports, for a given span between them is not therefore of indifference, as it would be, if the resistance were uniform.

Let us examine first the influence of this position.

The joint being the section of least resistance ought not to coincide with the sections of rupture, that is to say, with those points, at which, supposing the metal to be informly constituted, a maximum of molecular strain occurs; but, the position of the sections of rupture depends essentially upon the conditions, in which the rail is placed upon its supports.

The intermediate spans are generally admitted to be fixed; with fish-plates, this ought likewise to be allowed for the joint ones, for they maintain, incompletely no doubt, but to the same degree as absolute continuity itself, the rail constantly tangent to its end supports.

We must determine then the position of the sections of rupture in a solid, supposed to be fixed at both ends, and submitted to the action of a moveable load.

Let a be the length of the solid (Pl. VIII, fig. 5), I the moment of inertia of the section, relatively to its horizontal axis, passing through the centre of gravity, l, any position whatever of the moveable load P, relatively to the end A, ρ the radius of curvature at any point whatever, μ the moment of fracture at B, π the shearing strain at the same point, or, since only one span is being considered, the vertical reaction of the support B; and neglecting, as is usually done, the centrifugal force of the load, and the inertia of the rail, we have.

Between A and M,

$$(1) \qquad \frac{\mathrm{EI}}{\rho} = \mathrm{P}(l-x) - \pi(a-x) + \mu;$$

x being comprised between 0 and l;

And between M and B

$$(2) \qquad \frac{\mathrm{EI}}{\rho} = -\pi(a-x) + \mu;$$

x being comprised between l and a.

Replacing ρ by its approximate value $\dfrac{1}{\frac{d^2y}{dx^2}}$; integrating twice; and, when $x=a$, the differential equation of the first order gives $\dfrac{dy}{dx}=0$; and the equation in finite quantities $y=0$; we have, between π and μ the two following equations,

$$\frac{\pi a^2}{2} = \mu a + \frac{\mathrm{P}l^2}{2}, \quad \text{and} \quad \frac{\pi a^3}{3} = \frac{\mu a^2}{2} + \frac{\mathrm{P}l^2 a}{2} - \frac{\mathrm{P}l^3}{6}$$

whence,

$$\pi = \mathrm{P}\frac{l^2}{a^2}\left(3 - \frac{2l}{a}\right); \qquad \mu = \frac{\mathrm{P}l^2}{a} - \frac{\mathrm{P}l^3}{a^2}$$

inserting these values in (1), we have,

$$\frac{\mathrm{EI}}{\rho} = \mathrm{P}\left(l - 2\frac{l^2}{a} + \frac{l^3}{a^2}\right) - \mathrm{P}x\left(1 - \frac{3l^2}{a^2} + \frac{2l^3}{a^3}\right).$$

The greatest numerical value of $\dfrac{1}{\rho}$ corresponds to one of the extreme values of x; viz, when $x=0$, then

$$\frac{1}{\rho'} = \frac{\mathrm{P}l}{\mathrm{EI}}\left(1 - \frac{2l}{a} + \frac{l^2}{a^2}\right);$$

and when $x=l$, then

$$\frac{1}{\rho''} = \frac{-2\mathrm{P}l^2}{\mathrm{EI}.a}\left(1 - \frac{2l}{a} + \frac{l^2}{a^2}\right);$$

whence, if the sign be left out, as relating only to the direction of the curvature, $\frac{1}{\rho'} : \frac{1}{\rho''} :: 1 : \frac{2l}{a}$; consequently, as R′ and R″ express the molecular strain developed in the extreme fibres of these sections, supposed to be equal, and since $\frac{EV}{\rho'} = R'$, and $\frac{EV}{\rho''} = R''$, V being the half height of the rail, we have $R' : R'' :: \frac{a}{2} : l$.

The section of rupture between A and M, is therefore at A, so long as $l < \frac{a}{2}$; and at M, when $l > \frac{a}{2}$.

But, as the section of rupture of the segment MB is then at B, the most dangerous section is always, ***that of the fixed end nearest to the load:*** it changes from one fixed end to the other, as soon as the load reaches the centre.

Let l_1 be the distance from the load to the nearest end; its corresponding amount of strain,

$$R_1 = \frac{VPl_1}{I}\left(1 - \frac{2l_1}{a} + \frac{l_1^2}{a^2}\right) \text{ is greatest, when } \frac{l_1}{a} = \frac{1}{3},$$

a value which suits, since l is comprised between 0 and $\frac{a}{2}$: this maximum value therefore is $R_{max} = \frac{4}{27} \cdot \frac{VPa}{I}$

One of the end sections is therefore, in every position of the load, the one, where the strain is greatest; equality, between the strains, developed in these two end sections, and in the central one, only takes place, at the instant, when the load reaches the last named; it is, when the load reaches a third of the length, that the strain is greatest, and is situate at the end nearest to it.

Therefore, allowing that the ends are fixed, the joint being the section of least resistance, ought, as a natural consequence, to be placed unsupported in the middle, and not upon a sleeper; for this last position is theoretically the most unfavourable of all.

It is, because the load is considered at the centre only, that engineers look upon it as indifferent, in regard to the theoretical amount of strain upon the joint, whether it occur upon a support, or at the centre; the maximum strain with equal sections, is in reality $\frac{4}{27} \cdot \frac{VPa}{I}$ in one case, and $\frac{1}{8} \cdot \frac{VPa}{I}$ in the other; a difference which ought not to be overlooked.

69. *Strains on the metal in rails.* — For the 72[lb] double-headed rail of the Northern of France, we have in units of an inch,

$$I = 0{\cdot}014{,}908{,}985 \mid V = 2\ 66'' \mid a = 35.4'', \text{ whence } R = 934.7P.$$

For the inverted ⊤ rail of the Bourbonnais line,

$$I = 0{\cdot}014{,}415 \mid V = 2\ 56'' \mid a = 39.37'', \text{ whence } R_1 = 1{,}034.4P.$$

and for the new inverted ⊤ rail of the Eastern of France

$$I = 0{\cdot}012{,}341{,}100 \mid V = 2.36'' \mid a = 44.33'', \text{ whence } R_2 = 1{,}255.9P.$$

The value of $a = 3'.8\frac{1}{2}''$ does not apply, except upon those portions of the Eastern line, travelled over by trains of moderate speed and weight. The rail, $19'{\cdot}8''$, long rests in this case upon six sleepers, the two central spans are $3'{\cdot}8\frac{1}{2}''$ each; the two next are $3'{\cdot}6\frac{1}{2}''$ each, and the two end ones $2'{\cdot}7''$ each.

Upon lines of great speed and traffic, such as the Paris and Strasburg, the Paris and Mulhousen, the Frouard-Forbach, the Strasburg and Bâle, the number of sleepers is increased to seven.

For a statical load upon the rails of 13 tons per axle, $P = 6\frac{1}{2}^{\text{tons}}$, whence $R = 3^{\text{tons}}\,18\frac{1}{2}^{\text{cwt}}$, $R_1 = 4^{\text{tons}}\,6\frac{3}{4}^{\text{cwt}}$, and $R_2 = 5^{\text{tons}}\,5\frac{1}{4}^{\text{cwt}}$ per square inch.

Even with the supposition which is admitted above, these figures may be by accident considerably exceeded, not only in consequence of the variable conditions of the resistance of the supports, and of the distribution of the load upon the adjacent spans; but also through the condition of the motion itself, which, apart from concussions, causes to intervene, 1[st] a periodical excess of loading, due to the dead weights of the driving wheels exceeding the vertical equilibrium, and to the strain of the couplings; 2[dly] the pressure of the flanges upon the rails; and 3[dly] the differences between the actual distribution, and that originally calculated; and which are after a certain lapse of time, often very considerable.

But if all these aggravating causes, be neglected, on the contrary, a very unfavourable hypothesis, which fortunately is not exact, is formed; viz, the concentration of the load upon a single point (53). The pressure due to the same vertical load depends moreover upon a variable element, the distance between the axles of the locomotives; which also influences the conditions in which the spans are successively placed. Let us take, for example, the Vignoles rail, upon seven sleepers, and the locomotive with eight coupled wheels (the old uncoupled Engerth make of the Eastern of France). If the second set of wheels be made to slide over the first in Pl. VIII, fig. 1, it will be seen, that the most favourable

situation of the rail, is when they are placed, relatively to one another as in N° 1, each wheel being close to a support; and the most unfavourable one takes place in the position N° 2, the wheel c being in the middle of a 3'·0" span, while the adjoining spans are without any load.

It certainly is useful to place the sleepers at short distances apart from each other, but it is less so however, than might at first be supposed; since the axles of the locomotives being then much farther apart, than are the supports, the proximity of these latter has oftener the effect of isolating each span as it were, by removing them all still more from the condition of having their ends fixed. All that can be said of this generally admitted theory, even after making allowance for the want of fixity of the supports, is, that the rigidity is realized to a certain degree, but only momentarily; and merely when the load is applied in a certain way, where the approximation to symmetry can alone hinder the transverse inclination of the supports, and maintain the yielding surface nearly horizontal upon its supports.

Thus it may possibly be admitted, that a span is fixed at both ends, when it is reached by the centre wheels of a locomotive, having its axles sufficiently close together, to allow of its end wheels being at the same time upon the spans on each side of the first named one; and provided the distribution of the weight of the engine is not too unequal.

Such is the case, for example, for certain locomotives having six wheels coupled, of small diameter, and very near together. The span can by no means be considered as fixed, when reached by one of the end wheels; in fact, it is necessary to treat the rail, as a continuous girder, where the very small spans are only loaded at a single point; to trace the moments of rupture corresponding to the different modes of distribution of the load; and to be certain, that the greatest moment does not exceed, that of the resistance of the rail, calculated for a given strain on the extreme fibres.

But the results obtained by the application of this method, so useful in bridge calculations, would here have no interest in consequence of the variable and uncertain compression of the supports. Hence we must be content to treat the matter summarily.

70. When only two contiguous spans are loaded, the central support may be considered as fixed; with the two others, it is nearer the fact to consider the rail as perfectly free, than to look upon them as fixed: the theory is more unfavourable, and hence but little inconvenience in adopting it; it is even necessary to do so in the case of the end span of the rail, when the continuity of the joint is not established by fish-plates.

It therefore is evidently sufficient (Pl. VIII, fig. 6), in the equations (1) and

(2) (68) to make $\mu = 0$; whence a' being the length of the span under these new conditions: we have

$$\pi = \frac{3}{2} P \frac{l^2}{a'^2}\left(1 - \frac{l}{3a'}\right)$$

inserting this value in the finite equation deduced from (1), we get

$$\frac{EI}{\rho} = Pl\left(1 - \frac{3}{2}\frac{l}{a'} + \frac{1}{2}\frac{l^2}{a'^2}\right) - Px\left(1 - \frac{3}{2}\frac{l^2}{a'^2} + \frac{1}{2}\frac{l^3}{a'^3}\right);$$

the absolute maximum is for one of the limits of x; viz, when $x = 0$,

(3) Whence $$\frac{EI}{\rho'} = Pl\left(1 - \frac{3}{2}\frac{l}{a'} + \frac{1}{2}\frac{l^2}{a'^2}\right);$$

if $x = l$,

(4) Then $$\frac{EI}{\rho''} = Pl\left(-\frac{3}{2}\frac{l}{a'} + \frac{2l^2}{a'^2} - \frac{1}{2}\frac{l^3}{a'^3}\right).$$

(3) is greatest when $\frac{l}{a'} = 0{\cdot}422$; when it becomes $\frac{EI}{\rho'} = 0{\cdot}1928\ Pa'$.

(4) is greatest when $\frac{l}{a'} = 0{\cdot}634$; when it becomes $\frac{EI}{\rho''} = 0{\cdot}108\ Pa'$.

The greatest strain takes place therefore at the fixed end, when the load is at the distance $0{\cdot}422\,a'$ from it; and the amount of it is $R = \frac{EV}{\rho'} = 0{\cdot}1928 \frac{VPa'}{I}$.

If the span be considered, as with the ends merely laid on its supports, the section of rupture would always coincide with the point of application of the load; the greatest strain would take place when the load reached the centre, and consequently is at that very point; its value there would be $R = 0{\cdot}25 \frac{VPa'}{I}$.

But this supposition can hardly be justified, except in the case of an end span without fish-plates, and of the adjoining unloaded span.

71. Let us consider the position of the joint, both unsupported, and on a sleeper. In the first case the joint can only be at the centre, or very nearly so, on account of the length of the fish- plate, which is almost equal to the reduced span; it is therefore only necessary to compare the greatest strain developed at the supports, with that at the centre, when, under the action of a moving load, the system passes successively through the conditions of being completely fixed, partially so, or not at all; in consequence of its connection with the contiguous, and differently loaded spans.

1st Let us find the position of the load with the ends both fixed, corresponding to the maximum strain in the section at the centre.

Between A and M (Pl. VIII, fig. 5) we have,

$$(5)\qquad \frac{\mathrm{EI}}{\rho} = \mathrm{P}l\left(1 - \frac{2l}{a} + \frac{l^2}{a^2}\right) - \mathrm{P}x\left(1 - \frac{3l^2}{a^2} + \frac{2l^3}{a^3}\right),$$

and between M and B,

$$(6)\qquad \frac{\mathrm{EI}}{\rho} = \mathrm{P}l\left(-\frac{2l}{a} + \frac{l^2}{a^2}\right) - \mathrm{P}x\left(-\frac{3l^2}{a^2} + \frac{2l^3}{a^3}\right).$$

When

$$x = \frac{a}{2};\quad (5)\text{ becomes } \frac{\mathrm{EI}}{\rho} = \mathrm{P}\left(l - \frac{a}{2} - \frac{l^2}{2a}\right);\quad \text{and (6) is } \frac{\mathrm{EI}}{\rho} = \frac{-\mathrm{P}l^2}{2a}.$$

The first expression is the proper one, if the segment AM includes the centre, that is to say if $l =$ at least $\frac{a}{2}$; and the second if $l =$ at most $\frac{a}{2}$.

Their greatest numerical value is respectively, for one the least, for the other the greatest of the values of l answering to them; i. e. with the limit, common to the two series of these values, $l = \frac{a}{2}$; and the corresponding value of R is,

$$\mathrm{R\ max.} = 0{\cdot}125\,\frac{\mathrm{VP}a}{\mathrm{I}}.$$

2dly In like manner it is found that, when fixed at one end only, the maximum strain at the centre corresponds with the application of the load at the same point; and has for its value:

$$\mathrm{R\ max.} = \frac{5}{32}\,\frac{\mathrm{VP}a}{\mathrm{I}}.$$

3dly For a solid, simply laid loose at the two ends, the maximum strain at the centre corresponds with the application of the load at the same point, and has for its value:

$$\mathrm{R\ max.}\ 0.25\,\frac{\mathrm{VP}a}{\mathrm{I}}.$$

72. The following table gives a summary of these results:

MAXIMUM OF STRAIN DEVELOPED WITH RAIL						
In the section.	Fixed at both ends.		Fixed at one end only.		Free at both ends.	
	Position of load.	Greatest value.	Position of load.	Greatest value.	Position of load.	Greatest value.
At end. . .	at $\frac{1}{3}$ of the length	$R=0{\cdot}148\frac{VPa}{I}$	at 0·422 of the length.	$R=0{\cdot}1924\frac{VPa}{I}$	Any where.	$R=0$
At centre. .	At centre.	$R=0{\cdot}125\frac{VPa}{I}$	At centre.	$R=0{\cdot}156\frac{VPa}{I}$	At centre.	$R=0{\cdot}25\frac{VPa}{I}$

Excluding the supposition of the span being free at both ends, the strain of the outer fibres will be, at the supports, $0{\cdot}1924\,\frac{VPa}{I}$; and at the centre only $0{\cdot}156\,\frac{VPa}{I}$. The joint ought therefore in preference to be non supported, at least as far as the resistance is concerned.

If however it is allowed, that the span may, at a given instant, be nearly in the conditions of a solid free at both ends, a supported joint is preferable; because the limit, which the maximum strain can then reach is, only $0{\cdot}1924\,\frac{VPa}{I}$, instead of $0{\cdot}25\,\frac{PVa}{I}$.

It may also be seen, that the ratio $\frac{2}{3}$, which is usually taken, as the theoretical difference between the intermediate, and the end spans for rails, where the joints are not rendered continuous, is not exact; it equalizes the strains in the section of rupture, only under the action of a load at the centre; and not under that of a moveable load. Allowing, as is generally done, that an intermediate span, a, in length, is fixed at both ends; and that an end one, a' in length, is so at one end only; the following ratio exists between them,

$$0.148\,a = 0.1924\,a'; \text{ whence } \frac{a'}{a} = 0.762.$$

If, before the use of fish-plates, experience assigned a much smaller value to this ratio, it was because at first it practically sought, rather to diminish the rebound of the joint, than to equalize the strains; which the reduction of the end span has effected by several evident reasons.

Such are the results, to which the theory, accepted by permanent way engineers, leads; and in making use of it more must not be expected from it, than it actually affords. When dealing with the comparison of the strains, rather than of their absolute values, it may be generally sufficient to consider their statical condition; but in truth much assistance could not be expected from calculation in a matter of this kind. If the deductions drawn from the theory of elastic solids are every day verified by practice in actual construction, it is because in addition to doing away with the inertia of the masses employed, the points, considered as fixed, are so in reality, or very nearly so; whilst the supports of the rails possess a compressibility, very useful without doubt, even indispensable, but which varies much between one support and another, as well as from day to day; thus setting calculation greatly at fault.

73. Besides if this compressibility is of importance, as far as sudden concussions are concerned, it is on the other hand unfavourable to the statical resistance of the rail on the mere score of distribution of the pressures, which takes place after the two supports, between which the load is supported, have given way somewhat.

If, for example, we take into consideration, four supports only, we have for the maximum molecular strain, under a load applied at the middle :

1° Supposing the two supports, between which the load is comprised, are perfectly inflexible, and sustain it by themselves; we have $R = \frac{VPa}{4l}$;

2° Supposing these two supports give, so that each of them singly supports $\frac{P}{2} - p$; the load p, varying according to the degree of compressibility of the ballast, and of the elasticity of the rail, is supported by the sleeper, as follows,

$$R' = \frac{Va}{2l}\left(\frac{P}{2} + p\right); \text{ then } R' - R = \frac{Vap}{2l}.$$

Moreover this compressibility in the supports has the effect, even when a somewhat uniform distribution of the load is still preserved, of altering very considerably the theory of their being considered as fixed, on account of the inclination of the various elements of the span over the two supports, which yield under the load comprised between them.

It has sometimes been even admitted, that each sleeper may become completely removed from the influence of the load; so unfavourable a supposition is by no means necessary, and could never actually occur on any line with ordinary maintenance : if however one believed, that such a thing might occur the necessary consequence would be, to abandon the custom of placing a joint on a sleeper, as the most unfavourable position of all; for the joint would then be liable to become, sometimes the middle, sometimes the end of a span; and thus in every case would be the section of greatest strain of a double span.

§ II. — Suspended Joints of the Vignoles rail on the German Railways.

74. With the double-headed rail, the self-supporting joint is a natural consequence of the use of fish-plates; as they are ill-suited to a chair at the joint, which would have to be much wider, than the others. A chair has been used with a single cheek of extra length, doing away, to a certain extent, with the outside fish-plate.

This arrangement does not appear so good, as one employed on the line from Naples to Rome; both fish-plates are retained, and the two centre bolts passed through the single cheek of the chair, which is of the ordinary length; there being but a slightly raised edge to the bottom of the chair, as a substitute for the inside cheek.

With the Vignoles rail, it seems to be only natural, that the joint should rest on a sleeper; indeed as long as it was a question of applying fish-plates to existing lines, there could be no doubt on the subject: another advantage the inverted ⊤ rail has over the double-headed one, is that it dispenses with that extra care in adzing the sleepers, which the latter requires.

In Germany, as elsewhere, generally the inverted ⊤ rail with fish-plates was laid in this manner, latterly however the suspended joint has been advocated by many German engineers; several trials have been made, the results appeared satisfactory, and at present this method of permanent way has a tolerable number of advocates. We cannot therefore be silent on the subject.

The first trial, which took place in 1856, was made on the "Charles-Louis", railway in Gallicia, between the stations of Bochnia and Stocwina : a permanent set was soon observed in the spans where the joints occurred; and at the end of six years, the experiment was abandoned. It was resumed in 1858 on the railway between Küfstein and Innsprück, near to the Brixlegg station; there also the results were so poor, that by 1860 they had returned to the joint sleeper. From the information, which I gathered on the spot in 1865, this want of success was owing to exaggeration in the joint span; which was rendered considerably worse by certain curves, one of which was only of 14 chains radius.

The result was quite different, on the line from Lübeck to Buchen, where the experiment was also tried in the year 1858 : but here the fish-plates were 18″ long, and there was only 16″ between the insides of the sleepers (Pl. IV, fig. 19 and 20).

Greater steadiness of the sleepers, less loosening in the bolts of the fish-plates, smoother joints, and more easy maintenance, are the advantages, which were derived from the experience of more than seven years.

At first suspended joints were used only in straights; but in 1865 they were applied also to curves, without the least inconvenience resulting; in no case however, on the line itself, was the radius less than 45 chains. Quite lately the suspended joint has been used together with that on the sleeper in very sharp curves, like crossings, etc.; in order to diminish the inconvenience to the plate layers, arising from the unequal length of the inner and outer arcs, where the joints of both rails ought to come upon the same sleeper.

An experiment, made in 1861, on the Cologne and Bingen branch of the

Rhenish Railway, with the joint spans 2′·1″ long, induced the engineers of it to approve of the plan; and to desire its being generally used, provided the shoulders of the rail were not too sloping. This restriction could only have been made in fear of the more serious consequences which might follow from the breaking of a bolt, or of a fish-plate with an unsupported joint; for, "ceteris paribus," the connections at the joint have, at least as much strain to bear, when on a sleeper, as if the joint were suspended (68).

More than six years ago, on several parts of the Westphalian line, the joints were made self-supporting, and have answered perfectly well : in 1861 the same was done on a length of 550 yards, close to the Niederau Station, on the line from Leipsig to Dresden; the span being, between the two sleepers of each side of the joint 2′·0″, from centre to centre; between each of these, and the next one beyond it, 2′·9″; and between all other intermediate ones 3′·8″; the rail resting directly on the sleeper itself.

These experiments also proved favourable to unsupported joints; as the ends of the rails are better preserved, and the sleepers near to the joint are firmer, than with the ordinary manner of laying them. The great length of the fish-plates must however be taken into account, extending to the sleepers themselves, and even a little over them. This result especially excited the interest of the meeting of German engineers; who recognised the utility of renewing, and of somewhat varying the experiment.

On the Main and Neckar Railway it had previously been tried, and abandoned; but in 1863, it was renewed, and this time on a large scale; the result was very successful, the motion of the trains was easier, and the wear of the rails less; here also the fish-plates project about 1″ on to the sleepers, at each side of the joint. On the Upper Silesia Railway (Breslau to Posen), the engineers, after a single trial extending no farther back than 1864, were of opinion, that the suspension of the joints rendered them smoother, and might also possess other advantages; but this only in straights.

The system was tried about the same time on the Western of Saxony Railway; and has so far produced a decidedly favourable result, both, in curves, and in straights.

Still more recent experience, on the railway of Lower Silesia and the Marches in 1865, in straights only however, has been equally successful : one of the arguments made use of, in favour of the unsupported joint on this line, is, that the joint sleeper is more liable, than the others to become unpacked by the jumping motion imparted to it, if the fish-plate becomes at all loose; it then is more or less removed from the influence of a heavy load, so that the joint span, instead of being the shortest, becomes the longest. This argument has

but little weight; it is based no doubt on a possibility, but one that a careful maintenance can, and ought to avoid.

The results were equally satisfactory on the Northern of Austria Railway, "Emperor Ferdinand"; only that the very low rail, 3" high, and the very short fish-plates, were not well suited for this arrangement; the sleepers, on each side of the joint, having to be placed so close together, as to render them difficult to pack up.

The advantages resulting from it, appeared to be sufficiently conclusive, on the railway between Aix-la-Chapelle and Dusseldorf, to permit of the system being recently applied on a large scale. The change was extended a short time ago to a portion of the Eastern of Saxony Railway; it is most satisfactory in all respects; but has not however been applied to curves of small radius.

An experiment has been also tried on the railway of the Palatinate; the joint spans are 2'·0" from centre to centre; joint plates are used, only in curves, on the two sleepers of the outside rail, next beyond those on each side of the joint.

It is on the Holstein railways, that this alteration has been most extensively applied; first tried on a length of about one mile near the Neumunster Station, on the line from Altona to Kiel, with 2'·0" joint spans, and 18" fish-plates, it gave such good results, that it has been adopted for the new lines, from Neumunster to Neustadt; from Kiel to Ascheberg; and from Altona to Blanken. At Neumunster, as at Niederau, it was ascertained, that the different elements of the permanent way are by it rendered firmer; and that it requires packing less frequently, particularly near the joints.

Hanover also sides with the advocates of the alteration; but the application, which has been made, is too recent for a decided opinion to be given as yet.

In the opinion of the proprietors of the mineral lines from Grätz to Göflach, in Styria, the concussions, which are very perceptible with the supported joint, are much less so with the suspended one: this remark may have some interest for purely mineral lines, as their permanent way is necessarily less looked to, than that of more important lines.

The engineers of the following lines, Magdeburg to Leipzig, Saarbrüke, Treves, Rhein-Nähe, Eastern of Prussia, Cologne and Minden, Wilhelm, and Thuringia have reserved their opinion, in consequence of the short duration of their observations.

Others, few in number, are decidedly against the change; they condemn it "a priori," without having even tried it.

Thus the Mecklenburg railway admits the unsupported joint for the chair rail, but it does not see any reason for applying it to the Vignoles rail, as the joint, being a weak point, is better resting on its own support: the Berlin and

Hamburg line is of the same opinion ; the Nassau line is still more decidedly adverse to the change, especially in curves, " as a mere loosening of the bolts might cause a running off the line; " in this form, the objection has no foundation, since it is independant of the position of the joint : for if the joints were so loose, so as to allow the second rail reached to project into the interior of the line, a running off could take place as easily, with the joint on a sleeper, as with it unsupported.

75. In fine, a great majority of the numerous lines, which have devoted their attention to the question, one of much interest at the present time in Germany seem to be in favour of the modification, without producing however one really decisive argument for the change.

The general results of prolonged experience cannot be questioned; but do the advantages, which they point out, really refer to the unsupported position of the joint? Are they not partly at least, a consequence of the reduction of the length of the bearing, which diminishes the inconvenience of defective fish-plates?

If in fact the ends of the rails wear less, and the sleepers become less unpacked; or in other words, if these results are produced with the joint sleeper, may it not be the fault of defective fishing, which does not sufficiently produce continuity in the end spans, in fact rendering them the longest; and which does not do away with the rebound, as it ought to do?

If the unsupported joint is actually in itself preferable to the supported one; or if it affords, under the same conditions of maintenance, greater firmness to the permanent way, or more durability to the rails, the advantage ought soon to show itself on those lines, which use at the same time, the two methods; for example, on the Northern of France line, which has the double-headed rail, with suspended joint, and the Vignoles rail, with the supported joint : now the latter has proved itself quite as good, as the former.

A slight advantage may, however, as has been shown (68), be adduced in favour of the latter method, and which was pointed out some time ago (*); viz, that of diminishing slightly the strains on the fish-plates, and consequently the deflection of the joint, even to equality in the length of the span; with the aid of this circumstance may be explained, up to a certain point, the facts noticed on the German Railways above quoted; and for which the engineers of those lines, do not appear to have sought, or at least assigned, a cause.

To the advantages, which they allege to have established, they add another;

(*) « Travaux d'art et voies des chemins de fer d'Allemagne, » 1857, page 223.

it is, that with non-supported joints, they are freed from the necessity of having two kinds of sleepers; one broader, and especially much longer, for the joints, and the other for intermediate sleepers.

Hardly any where but in Germany, is this condition of two different lengths imposed (133), the general custom being merely to place the broader, and more even sleepers at the joints; and it is found to answer. As the advocates of the suspended joint recognise the necessity of placing straight and even sleepers at each side of it, without which they would be difficult to pack up, owing to their nearness to each other, the advantages possessed by this arrangement on the score of sleepers are not very apparent.

76. The suspended joint, combined with the inverted ┬ rail is also in operation in England, on the London Chatham and Dover line; but, as has been already seen, it appears, as if the object had been to adhere as closely as possible to the method adopted in laying the double-headed rail; the position of the suspended joint appears then, in this case, to be a mere matter of imitation. In the United States also an attempt has been made, to lay the inverted ┬ rail with suspended joints (Pl. VI, fig. 12, 13 and 14); but it was in consequence of the form of rail itself, which was too low for the ordinary fish-plates, and in order to give these sufficient depth, they were prolonged beneath the rails, as has been since in some cases proposed in Europe (104); and hence a suspended joint was used.

Taking every thing into consideration, it may be considered almost a matter of indifference, as regards resistance, whether the joint be placed at the centre, or at the extremity of a span of a given length : in point of security, it may also seem unimportant, as it is very rare that fish-plates ever break; but, if there be any cause to distrust their solidity, they are better on a sleeper; as this position ought to lessen any evil consequences, arising from breaking.

The unsupported joint, so generally in use in England, however has been attacked among others by Mr Brunlees; who advocates the supported joint with a fish-plate chair, a necessary substitute for the fish-plate with double-headed rails (*).

77. The ratio between the end, and the intermediate spans, was decided upon before the use of fish-plates, mainly by the necessary condition of re-

(*) See "Railway accidents, Institution of Civil Engineers, Minutes of proceedings". Vol. 21 (1861-62), page 348.

ducing the rebound, and the oscillation of the rail (67) : it was thus determined to give the end span a length considerably less, than would correspond to an equal amount of strain for the rail in both spans. With fish-plates, the unequal distribution of the sleepers, ought to have no other object, than to compensate more, or less fully, for the inferior resistance of the joint; whether supported, or suspended.

We shall return to this point, after having examined the connection in itself.

§ III. — Fish-plates, number and disposition of the bolts

78. The arrangement of fish-plates, in Germany especially has been the object of many, and various experiments. Their essential duty being, to ensure the exact meeting of the ends of the rails, it is necessary to tie them together sufficiently close to the joint. Thus it is, that the fish-plate, with three bolts, one being at the joint itself, was considered by some engineers, more fitted to insure the complete level between the two rails : the immediate action of the body of the centre bolt, filling up at the same time the notches made at the end of both rails, is therefore counted upon to keep them exactly in position, relatively to one another. This arrangement however overlooks one of the most essential conditions of a good fish-plate, the freedom of the body of the bolts; which should only be subjected to a tensile strain, and be free from all contact with the body of the rails. The extent of the bearing of the web of the rail upon the bolt is not constant, on account of the excess of length given to the bolt-holes to allow for expansion : with four bolts however, the horizontal deflection of the segment, between the centre bolt holes of the fish-plates, compensates at least in part, for the want of level; which often exists, through the sections of the two rails not being exactly alike; this useful effect disappears, when, through the existence of a centre-bolt, this intermediate segment becomes null.

Again supposing the fixedness of the rail at each support to be only a temporary, and periodical condition, it is hardly logical to weaken the fish-plate in the middle; or, precisely in the part of the span, which receives the greatest strain, in the case of the supported joint, even supposing the resistance to be equal throughout; though the bolt-hole, it is true, occupies the place of metal, which has but little strain upon it; however this reduction in the section would be more serious, if the centre bolt was, as it ought to be, of a greater diameter, than the two end ones.

The employment of three bolts, introduced first in Hanover, was in use there for many years, without any grave defects being remarked; the bolts were $6\frac{3}{16}''$ from centre to centre, and all three were $\frac{7}{8}''$ in diameter; an equality which was evidently disproportionate; in course of time, it was remarked, that the transit over the joints, was more marked on the Hanoverian lines, than on others, which used four bolts.

In 1862 this last arrangement was adopted, and the motion of the trains is decidedly smoother on the new portions, to which it has been applied : this result undoubtedly is not entirely due to the addition of the fourth bolt; much of it may be ascribed to the rail itself, which is higher and heavier; to the fish-plates, being lengthened to 19″; and probably also to the suppression of the bed-plate, used with the original joint, which contributed certainly to the harshness of the joint; they were however intended to act with short fish-plates, joined by three bolts only. The slope of the bearing surfaces, both of the head, and of the foot, was an angle of 45°; the distance between the centres of the bolt-holes was, between the two middle ones $4\frac{3}{8}''$, and between the others $5\frac{1}{4}''$.

A trial made on the Berg railway, in Prussia, led also to the adoption of four bolts.

It is difficult to understand why two French Railway Companies, the Orleans, and the Mediterranean (Pl. V, fig. 16 to 25), recently adopted an arrangement, which had already been condemned by comparatively long experience; and which moreover effects, but a trifling economy.

79. In order to keep the nuts tight, stop pieces have sometimes been added to them, either at all the bolts, or only at the middle one; this addition, as well as that of keys (Pl. IV, fig. 19 and 20) is superfluous: for in spite of the vibrations, to which they are exposed, the nuts, except in the case of breakage, become very little loosened, unless the inclination of the thread is too great, as the rust soon renders them tight; it is rather this clogging, and the difficulties it throws in the way of screwing up, which it is necessary to prevent, lest the bolt might turn with the nuts; by forestalling the rust itself by keeping them well greased. In Mr Bernard's opinion, the nuts become unscrewed much less, if greased when first put on, and this be from time to time repeated, to preserve them from rust; in as much as breakages among them were frequent at the commencement, but are now much rarer since this has been done; which shows no doubt, that their becoming unscrewed was caused, either by the corrosion of the threads, or by the excess of strain, previously applied to the nuts, when caked up with rust.

80. Several attempts have been made to substitute rivets for bolts, but they soon become slackened. Although this question may be regarded as definitely settled, particularly by a long experience on the Thuringia line, the experiment has been again tried on the railway from Frankfort to Hanau; but without giving any better results.

In order to accept the use of rivets, with all the inconveniences attending them, they should be greatly superior in themselves to bolts; but the effect is quite the contrary. Without taking into consideration their great defect, that of becoming slack, it would often happen, no doubt, that in a line carelessly laid, a rivet, which was put in too hot, would have the effect of reducing the play between the rail, and the body of the rivet.

The bolts, fastening the fish-plates, I repeat, should not be subject to any transverse strain; for they are simply ties, which ought to be protected from any downward pressure from the rails, by an excess in the vertical diameter of the bolt-holes therein over that of the bolts themselves.

This essential condition has at times been singularly misunderstood; for example, on some German railways, the bolt-holes in the rails are made horizontally oval, to allow for expansion, and contraction, while vertically they are only equal to the diameter of the bolt: which is in fact doing a deal of harm, to obtain a very bad result; for, under the influence of the load, the web of the rail is pressed down upon the bolt, causing it to deflect; it is thus gradually forced into it, and finally destroys it. It is therefore indispensable not only to preserve horizontal play for expansion, but also vertical play to counteract deflection, and any defects in the plate laying; or the best is, as is now done nearly everywhere, to pierce the hole round, but considerably exceeding the size of the bolt, in order to preserve it from being pressed down upon by the rail.

The diameter of the bolt-holes, has been successively on the increase, partly it is true owing to a corresponding augmentation in the diameter of the bolts themselves; on the central section of the Orleans line, for example, the present diameter of the bolt holes is $1\frac{1}{4}''$, when several years ago it was but $\frac{7}{8}''$.

The holes in the fish-plates are generally filed, near the ends of the horizontal diameter, in order to fit into them small spurs, which are made on the bolts so as to prevent them turning round, whilst the nuts are being screwed on; this would be more easily effected by means of a groove in the fish-plates; an arrangement, which has not even the slight inconvenience, attributed to it, of requiring two kinds of fish-plates (Pl. V, fig. 6, 8 and 9).

81. The nuts of the fish-plate bolts are nearly always placed on the inside

of the line : in France, the Saint Germain des Fossés to Nevers branch of the Mediterranean line, and the small railway from Sceaux to Paris are the only exception to this rule. It is only in Germany, that the nuts are generally on the outside, on a great number of lines. The former arrangement is evidently the best, particularly when the sleepers are covered with ballast, as the inside face of the rail should always be kept free from it; even if the sleepers are uncovered, it is convenient to place the nuts on the inside; for it can then be seen with greater ease, and quickness, whether they are screwed up or not; especially if they are four-sided, and not hexagonal. Plate-layers might be instructed to place them on the square, with the sides upright, and to restore them to that position; thus, when walking in the centre of the way, they could at a glance see those nuts, which had altered from the upright position, unless the diversion was exactly a quarter turn; they could then tighten the nut, and place it again on the square, by the aid of some small washers, if necessary.

§ IV. — Form of the Rail most suitable to the Fish-plate.

82. In many rails, a firm hold cannot be got for the fish-plates, in consequence of the lower sides of the head of the rail sloping off too little from the web; in which case the head acts, when under the load, as a very sharp wedge, bends the fish-plates, and places an excessive strain on the bolts; by slightly rounding, and if necessary by increasing the thickness of the fish-plates, the first inconvenience might be got over, but it is difficult to do away with the second, as the diameter of the bolt is necessarily limited.

It is now generally agreed, that an essential element in designing the form of a rail is its adaptability for the use of fish-plates; opinion is any thing but unanimous however, in defining the angle most suitable between the web, and the lower side of the head, to facilitate the use of fish-plates. Whilst they have fearlessly gone as low as 73° on the Eastern of Prussia line, and to 75° on the line from Cologne to Minden; on the Bourbonnais line, it is no lower than 82° with a symmetrical double-headed rail, on the section from Nevers to Roanne; 83° on the Orleans, and on the Paris and Lyons; 90° on the Eastern of France line, with a Vignoles rail; 91° at top, and 106° at bottom, with an unequal headed rail on the same line; 95° on the Western of France, with a symmetrical double-headed rail; 118° on the Belgian Luxemburg line; 122° or 123° on the Northern of France (Pl. III, fig. 13), the Southern of France, the Western of Switzerland, the State railway of Austria, the Saragossa, and on the Main and Neckar line; 127° on the Bourbonnais with a Vignoles rail on the portion from Moret to Nevers; and

159°. in Austria, for the newly projected Bessemer steel rail (Pl. II, fig. 12), etc. (*)

The symmetrical rail of the Paris to Strasburg line has only an angle of 68°; this form, designed solely with a view to the resistance of the rail, is considered, as not admitting of the use of fish-plates, properly so called; the same object was held in view in those of the Western of France, of the Paris and Lyons, and of the Paris and Mulhousen lines, which might nevertheless be all well suited to the application of fish-plates, except perhaps that of the Mulhousen line; which might present an insufficient bearing surface in the smaller head. It would appear, that they have gone too far, in the case of the Eastern of Prussia rail: and are too cautious, on the contrary, on the Bourbonnais line, with the rail for the Moret to Nevers section, as well as in the Austrian Bessemer steel rail.

Two conditions must be fulfilled, 1st that the metal be distributed, suitably for the resistance of the rail; and 2nd that the grip of the fish-plates be good.

If the angle is too great, the unsupported parts of the head, having no shoulder to connect them, have nothing to sustain them; the rail is thus sacrificed, and without any real benefit to the fish-plate; as the tensile strain on the bolts is sufficiently reduced, without the bearing surface being brought so near to the horizontal. With too sharp an angle, this tension becomes too great, whilst the rail gains nothing; for the projecting sides would have been sufficiently supported with a wider opening.

To choose between the two extremes, the rail of the Eastern of Prussia line appears to be the most preferable; for the form of the rail is doubtless better in itself, and the fish-plates, as experience proves, hold well; an angle of 100° to 120° appears to combine very suitably the two conditions; the strain on the bolts is not excessive, and, as to the rail itself, there is no reason for reducing the angle below this limit.

83. It is clear, that the need for the higher limit to the angle applies only to the upper head, or bearing surface; in the lower member, the smaller head of the non-symmetrical, and the foot of the inverted ⊤ rail, the opening may approach much more to the horizontal.

According to the late Mr Perdonnet the same slope is necessary in both members.

(*) In those sections without dimensions, the angles were simply taken with a protractor; they are not therefore rigorously exact, but sufficiently so for the object now in view.

" In order (*), " he says " that the ordinary fish-plate may perform its duty effec-
" tively, the section of the rail must comply with the two following conditions:
" The bearing surface of the shoulders should be even, and also alike; a condition
" necessarily fulfilled by the double-headed symmetrical rail; but for the single-headed
" chair-rail, or the Vignoles rail, they must be designed especially with respect to the
" fish-plates, in order to present the required symmetry of surface, in the shoulders. "

While, thus laying down in principle, this necessity for their being alike, both in the upper and lower members, Mr Perdonnet therein sees an objection to the simple fish-plate, to which he prefers the fish-plate chair for chair-rails, and especially for those with unequal heads. Even were the principle established, it would still be necessary to assign a cause for this preference; if it appears natural enough to give the upper and lower bearing surfaces an equal slope, as is often done, no inconvenience arises to the fish-plates, in giving a larger angle for the opening of the lower bearing surface, which is done very often, in order to distribute the metal more suitably to the different duties of the two members; as in the case of the Eastern of France Railway (1st and 2nd types, Pl. III, fig. 12), of that from Grenoble to Saint Rambert (Pl. V, fig. 5), of the "Gebirg's Bahn" (fig. 28), of the Central of Switzerland (Pl. II, fig. 10; etc.). To speak with preciseness the inconvenience, if it is one, resolves itself into the fact, that the form of the fish-plate, not being exactly the same on its upper, and on its lower face, fits badly, if it is placed upside down; but with a distinct mark, which these kind of fish-plates always have, it is impossible to commit an error of this nature. Such is, for example, the object of the little projection, *b*, which the fish-plates on the "Gebirg's Bahn" of Silesia have on the inside face (Pl. V, fig. 28), and those of the Eastern of France on the outside (Pl. V, fig. 30); on the first-named line this projection should be placed at the bottom, and at the top on the second one.

The bearing surfaces of fish-plates are not always flat; in the Semering rail, for example (Pl. II, fig. 15), and on that of the Vienna and Raab line (Pl. V, fig. 35), the surface is round; in the rail of the Austrian " Staat's Bahn " (Pl. V, fig. 34) it is formed of a straight line, $1\frac{1}{2}''$ long, inclined at an angle of 61° from the vertical, and tangent to the arc of a circle, having a radius of $\frac{7}{8}''$; on the Eastern of France, the shoulders of the head are straight, and inclined at an angle of 45°; but those of the foot are circular, of $\frac{3}{4}''$ radius (Pl. V., fig. 30). This form appears defective; for contact is established with surfaces more or less inclined from the vertical, according as the initial tension of the bolt is

(*) " Traité élémentaire des chemins de fer, " 3e edition. Vol. II, page 39.

more, or less in amount; so that the tension due to the same load, depends on the degree of screwing up which previously exists; the strain therefore on the bolt is very uncertain in its intensity.

§ V. — Modifications of Fish-Plates.

64. If, whether rightly or not, the angle forming the head is considered too acute, there are but two methods of remedying it; either to alter the form of the rail, where the fish-plates grip; or else, if it be a chair-rail, to do away with the fish-plate, properly so called, and to have recourse to one of the expedients mentioned further on (93 and 95).

The very evident influence of the obliquity of the bearing surface of the fish-plates on the resistance of the joint has been estimated by many experiments of Mr Weishaupt. Two rail ends, joined by fish-plates with four bolts, and forming a 3′·1″ span, were submitted to the action of the lever press (19); the deflection varied from $\frac{3}{8}''$ to $\frac{5}{8}''$ under a load of from $2^{tons}\,14^{cwt.}$ to 3^{tons}; the load, which caused rupture was from $4^{tons}\,4^{cwt}$ to $5^{tons}\,4^{cwt}$; the fish-plates began to bend, when the weight reached from 2^{tons} to $2\frac{1}{2}^{tons}$. An experiment was then made with fish-plates, having the same section, but rectangular in form, which fitted into notches of the same shape, made in the head and foot; the intermediate bolts were also brought nearer to each other, to prevent more effectually the tendency of the fish-plates to bend, which was most marked towards their centre, but which however had already been somewhat diminished by their shape: these alterations had the effect of augmenting the breaking weight up to from $6^{tons}\,8^{cwt}$ to $6^{tons}\,17^{cwt}$; or an addition of 5 per 100.

It was at the conclusion of these experiments, that the above arrangement, which had already been tried in Wurtemburg, was adopted in relaying the old line from Berlin to Frankfort-on-the-Oder; this was however soon given up, it being considered simpler to counteract the strains, developed at the joint, by bringing the sleepers on each side of it nearer together, an insufficient remedy however, than to increase the resistance of the joint by a method of adjustment, which is certainly not free from inconvenience.

It is especially near the ends of the rail, that the welding is imperfect; nor does it certainly appear expedient to soften the iron in this part, precisely where the fish-plates bear, and at the point where it is important to preserve all the hardness of the surface. A fish-plate, with notches made to fit it, has been however adopted in France, for the central portion of the Orleans line; where the rail is nearly that of the Prussian "Ministerial" (Pl. II, fig. 9), except that the angle of the bearing surface of the head is a little less acute, and

it is somewhat thicker in the web : the operation, performed on both sides at once by means of a punching machine, is easy, and costs but little; so that there is no objection on this score.

Experience however will show, whether by this arrangement the fish-plates have not lost more, than they have gained; with the ordinary method, the inclination of the bearings compensates for minor irregularities in the shape of the rails and fish-plates; these latter, tightened more or less by the screwing up of the bolts, are always in contact with the head of the rail : the same is not the case, when there is no inclination, or a very slight one, as contact can only be established by absolute exactness in their shape, which it is easy however to obtain by some method of adjustment (*).

It is certain, that a rail may be perfectly capable of having fish-plates applied, with a straight, unbroken edge, without its being obliged to sacrifice any of the other essential conditions, which it should fulfil; it is difficult therefore to understand why forms of rails, not adapted for fish-plates, should be used, entailing as a necessary consequence, the constant repair of the rail ends.

85. On the "Gebirg's-Bahn" of Silesia, but one kind of fish-plate has been adhered to, both for the outside, and the inside of the line. On their outer face, they have two projections *e.e.* (Pl. V, fig. 28) forming a groove, in which is set the oblong head of the bolt, which cannot then turn; whilst the hexagon nut, turns easily between them. The diameter of the bolt-holes in the fish-plates is a little larger, than that of the bolts, $\frac{7}{8}''$ and $\frac{15}{16}''$, in order to compensate for any slight irregularities in the form of the rail, or of the fish-plates; the bolt-holes in the rail are large enough to prevent any contact between the web and the bolts, and are made slightly elliptical $1\frac{1}{4}''$ by $1\frac{1}{16}''$.

To prevent any bending of the fish-plate in its middle part, the two centre bolts should not be too far apart; but the outside bolt-hole of each rail must also be sufficiently far from its end, to prevent the web splitting horizontally, under the strain of the fish-plates; this distance has been fixed at $1\frac{1}{2}''$ which with a web $\frac{5}{8}''$ in thickness gives a horizontal section of $\frac{15}{16}$ of a square inch.

A great many different pieces have been grouped together in this form of connexion; viz. a joint plate; lateral cover joints *l.l.* resting on the foot of the rail; strips of tarred felt *f.f.*, placed below the cover joint, and upon the joint plate and the rail, in order to counteract any little inequalities in thickness, and to

(*) The Orleans Railway C°, seeing the inutility of this arrangement, have discarded it.

insure contact in both cases; a bottom plate *i* (fig. 28 and 29), on which rest the heads of the two screw bolts, having their nuts above, and which fasten the whole; these bottom plates have a raised edge, *r*, against which rests one of the faces of the hexagonal headed bolt, thus preventing its rotation.

Instead of plain holes, these plates have grooves, *m*, *m*, in them, to accommodate themselves to the different positions the bolt assumes, in consequence of the increased width of the line in curves; and which allow of the plate being raised, without the bolts being taken out. The tarred felt bands are only placed in position, when the line is definitively laid, and in order; the plate-layer should then be furnished with warm water to soften the felt.

This system of joint, to which we shall again revert, when treating of laying the line in curves, has been studied with much care : it contains however certain complications, against which experience has definitively decided.

86. The fear of the nuts becoming unscrewed has suggested (79), to overcome this defect, sometimes simple details, such as on the Holstein Railways, from Lübeck to Buchen (Pl. IV, fig. 19 and 20), by the addition of a stop nut, or of a key; or again others more complicated, such as the ingenious modifications, which the London Permanent Way C° have introduced, though they are not generally used (Pl. V, fig. 31). Here the bolts are replaced by two screws, *v*. *v*. having their threads in opposite directions, like the coupling screws of a railway carriage, and each having a square-cut head; the fish-plates, screw-tapped, form the nuts.

Mr Wilson has adopted this arrangement on the Indian Railways, already spoken of (57).

In itself, it is sufficiently ingenious; but it necessitates a precision, and an exactness of form, very difficult to obtain; for, should the socket holes in the fish-plates not correspond exactly with the screws, these become bent, and work no longer under their original conditions.

There is no difficulty in laying this arrangement of permanent way; the four screws of one fish-plate are first fitted into it, they are then passed through the holes in the rails; and on the second fish-plate being put into its place, the four screws are tightened with an ordinary key, only half a turn being given at a time to each, until the two plates are in contact with the rails; they are, then, finally secured by means of a double forked lever key, L, which takes hold of both the heads of each screw, at the same time (fig. 31).

87. In England, an attempt has even been made to do away with bolts and nuts; using, instead of fish-plates, a sort of spring clip *m*, *m* (Pl. VI, fig. 15 to 18), wrapping round the lower head, and the web of the two adjoining rails;

it is forced open to receive them, and grips them closely, by reason of its elasticity. A very slight thickness only can be given to this elastic plate; otherwise, it could not be got into its place without great difficulty; if the lower head is but small, ties through the rail appear to be the simplest, and surest means of counteracting the considerable thrust to which the fish-plate is subjected.

88. The first fish-plates were made to fit exactly into the throat of the rail, and were pressed close against the web; this form had two great defects; 1st the essential condition of close contact, between the fish-plates, and the heads of the rail, could not always be obtained, even by screwing up the bolts to the utmost; and 2ndly the fish-plates, being thickened out, at the centre of their height, were ill-adapted to resist transverse strain.

They are made now-a-days of an almost uniform thickness, which, whether curved out, or not in the middle, (Pl. IV, fig. 1, 3 etc. fig. 18, 20 and 22; Pl. V, fig. 2), leaves a space between the fish-plates and the body of the rail; thus ensuring an exact fitting between the plate, and the edges of the heads of the rails. Sometimes the fish-plate is swelled out near the inside edge, to augment its resistance to deflection, and to increase its bearing surface on the rail; as for example on the Cologne and Minden, (Pl. IV, fig. 14), on the Lübeck to Buchen, (fig. 20), on the Northern of Spain, (fig. 14 and 38), and on the Mediterranean line, (Pl. V, fig. 18, 22, 23, 25).

It has been the subject of much discussion, whether the cross section of the fish-plate ought to be uniform; the moment of resistance should in each half increase from the extremity up to the intermediate bolt-hole, from which point it should be constant; the section, comprised between the two middle bolts being, as far as regards vertical resistance, acted upon doubly; but, as the height of the fish-plate is of necessity fixed, it is only its thickness, that can be increased. Mr W. Bridges Adams has proposed a fish-plate approaching in form to that of equal resistance; but this complication only produces a slight saving in material, whilst it increases its flexibility, and consequently that of the joint, to the degree of maximum strain on the fish-plate.

89. On the line from Lübeck to Buchen, in place of ordinary fish-plates, a single very thick plate is placed outside, with a projection which has somewhat the same contour, as that of the rail, and nearly the same amount of section (Pl. IV, fig. 15 and 16); the comparative experiments of rupture made on this system, and on others with the ordinary double fish-plates, have shown a considerable advantage in favour of the former arrangement; but this is the result of its dimensions used, and in no way of the principle itself.

The object however in view in thus sacrificing the similarity between the sides at the joint, is not so much to increase the resistance, as to counteract any defect in the screwing up of either of the two rails, when they are not exactly of the same thickness, and to obtain a greater precision in the junction of the ends; an effect, which this one-sided fish-plate system realizes less, than does the ordinary one, in fact nothing warrants us in expecting it to do at all as well. There is only one case, when there may be some cause for this arrangement, and that is, when two rails of different forms come together; then the single fish-plate should, apart from its large cross section, be formed of two halves, each adapted to the rail, which is to receive it; take, for example, the State railway in Austria Pl. V, fig. 33.

§ VI. — Strengthening of the joint with the chair-rail.

90. Although, the chair may be looked upon as a thing of the past, its combination with the fish-plate, is nevertheless of great importance for lines where the chair rail is used; the most should be made of such railways, so as to afford them all the advantages, of additional security, of economy in maintenance, as well as any other improvements suited to them.

There are in use four different methods for the formation of the joints with double-headed rails.

1st The ordinary fish-plates, with a joint chair, sufficiently wide to receive the fish-plates and the wedge.

2nd Ordinary fish-plates, with an unsupported joint.

3rd Angle-iron fish-plates.

4th Fish-plate chairs.

91. *First method.*—This was first applied on the line from Dusseldorf to Elberfeld; on which, owing to the addition of fish-plates, the wear of its unequal headed rail, which previously had become too weak for the rolling stock, was lengthened by several years; the wooden wedge was replaced by an iron key, in order to diminish the width of the chair.

The chair joint has been also adhered to on the Taunus line, its size admitting of the adoption of a wooden wedge, by countersinking the heads of the bolts of the fish-plates.

92. *Second method.*—In Germany, where the double-headed rail is but little used, there is not to be found a single example of the unsupported joint; in England, on the contrary, this arrangement is general, and this sufficed

to ensure its adoption in France. It seemed in some way natural, that Germany and England should have adopted without discussion these two different solutions of the same problem; in as much as fish-plates, when first used, were applied to already existing lines; with the inverted T rail they simply required to be fitted on, without any change in the arrangement of the supports, it was therefore very easy to take advantage of this form of joint; in England it was likewise the simplicity of the unsupported joint, dispensing with the use of any specially made chair, which led mainly to its adoption; it is true that on the other hand it necessitated a different arrangement of the sleepers, an expensive operation, but more or less exempt from the delays, which often attend the manufacture of special chairs. Sometimes an extra sleeper has been added, which is an additional expense; as is the case on the Northern of France line, in the application of fish-plates to 19′·8″ rails placed on seven sleepers.

The formation of the joint, properly so called, has cost on this railway 3s·9d per joint, in the following manner.

	lbs.	s. d.
Outside fish-plate, with groove, weighing.	10	
Inside fish-plate, without groove, ...	11	2·11
lbs.	21	
Being at £15·10·0 per ton.		
4 Bolts and nuts, weighing 3½ lbs each at £25 10·0 per ton.		0·10
		3·09

Or, with the 19′·8″ rail, £ 206 per mile, of double way.

If it be an already existing line, to which this arrangement is applied, a further expense must be added, of at least £100 per mile of double way, for taking the line to pieces, and putting it together again, as well as for punching new bolt-holes on the ground itself; bringing up the total cost of the change, the number of sleepers remaining the same, to at least £300 per mile of double way. It would therefore be anything, but economy while laying a line, to postpone making the joints unsupported till some future time.

Figures 21 to 29, Pl. VI, show the unsupported fish-plate joint, in use on the Southern of France railway; where some unfortunate applications of the Bridge rail on longitudinal sleepers (120 and following paragraphs), and of the Barlow rail, simply resulted in the chair-rail being again adopted. The ratio between the spans, joint ones being 2′·0″, and the intermediate 3′·2″, is here reduced to 0·61, and the length of the fish-plate is increased to 1′·9″; which places the joint in very favourable circumstances, as regards resistance and stability.

98. *Third method, Angle-iron fish-plates.* — The idea of doing away with

the joint chair, without interfering with the sleepers, by lengthening the fish-plate sufficiently downwards and bending it at right angles, to give it by means of a wide base that stability, which the rail requires, seems very natural. It was applied in the year 1850, to a section of the Westphalian line (Pl. IV, fig. 29 and 30); two cheeks, or angle irons, were used, having in their upper portion nearly the outline of the rails, to which they were bolted; the lower half, doubled over at right angles on to the sleeper, was fastened to it by two bolts: they weigh about 10^{lbs} a piece. There is no joint plate; as with a joint arrangement, which entirely does away with any up and down movement, and which likewise ensures a considerable base for the support, it was considered, unnecessary to protect the wood by a metallic plate.

This method of joint has in fact answered well. Its resistance to breaking is considerable; it only gave way, with the same conditions already mentioned in other cases, under a weight of $12^{tons}\ 3^{cwt}$, or about half of the breaking weight of the rail; whilst though the bolts were broken, the fish-plates were scarcely bent.

This mode of applying fish-plates, to the lower member of rails, appears in certain instances, preferable to the two preceding methods; and especially to the second, when altering an existing line.

Fish-plates of this kind have also been applied on the Rhenish Railway; but it was thought necessary to add a large joint plate with ridges at the sides, between which the fish-plates are held.

This addition, though useless in this instance, would have been an indispensable one in the arrangement, tried on the Westphalian line with single-headed rails; in fact replacing the chair joint by fish-plates without any base, on a level with the foot of the rail, and only held between two spikes, embedded up to their heads in the sleeper. This attempt has not succeeded, nor could it do so: the want of width of the bearing surface was all the more apparent, since nothing in this case warranted the rail, and its adjuncts, being applied directly upon the joint-sleeper; the conditions of resistance of the bolts, and consequently that of the fish-plates themselves, were also completely changed; the former being exposed to work transversely, whenever the connection deflected, in consequence of the bearing of the fish-plates, on the very small lower head of the rail, being almost null.

94. At first, when applying the angle-iron fish-plates to the joints, the arrangement at the intermediate supports was not changed; but many engineers thought, that the method applied with success in the one case, would be equally so in the other. This change, on a line already laid, would be nearly all loss, for the intermediate chairs are far from being open to the same serious

charge, as are those at the joints; but the question is in itself however an interesting one.

All the chairs on one section of the Westphalian line were replaced by these fish-plates; the pair, each of which weighed 4 lbs, were fixed to the rail by the same rivet, and each of them to the sleeper by a wood screw : the riveting was made tight, so that the sleepers necessarily either prevented, or followed, the least variation in the length of the rail; a condition, which however would be but little altered by introducing a certain amount of play (121), except by some what loosening the rivets. It is only at the joints, where bolts are used, that there is any play for the rail with these fish-plates.

The success of this experiment was complete both in Westphalia, and on the line from Brunswick to Oschersleben; to which the same method was applied in 1853. This system presents, compared with chairs, certainly the advantages of economy and security, and probably that of longer wear, of affording smoother motion, and of more easy maintenance. Therefore some engineers have gone so far as to inquire, if this arrangement, thus relieved from the addition of the chair, might not even have an advantage over the inverted T rail. In Prussia a few did not hesitate to decide in the affirmative; this opinion may be somewhat plausible, but it will not bear a close examination.

Undoubtedly the arrangement in question unites the advantages belonging to the Vignoles rail, as well as to the double-headed one. That is to say, on one side of stability, properly so called, and of suppressing any up and down movement; and, on the other, of having the facility of being turned, which in this case can always be effected, whatever be the state to which the upper head is worn; for, as there are no chairs, the lower member will always present a smooth, uninjured surface, free from any blemishes usually caused by them : these are besides real advantages. The experiment on the Westphalian line, no doubt, aided in giving the last blow to the condemnation of the chair; but it did not at the same time restore confidence in the double-headed rail.

In this arrangement, as in the others, only in a greater degree, there are certain inconveniences. With a chair, to turn a rail is a very simple thing; with the angle-iron fish-plate, however it comprises not only the extraction, and the re-insertion of the wood screws, but it also necessitates that the rivet should be cut, and a fresh one put in its place; in fact a complete operation. Again, supposing the rivet hole correctly punched, and without any play, in the middle of the height of the rail when new, it will be so no longer when the upper head is worn and flattened, so that after the rail is turned the fish-plates alone bear on the sleeper, and not so the rail : besides the amount of wear is too uncertain for an allowance to be made beforehand, by placing the

hole a little below the centre. The maintenance of a line, in these circumstances would entail a very great difficulty, if indeed it were not wholly inadmissible, except for lines with so little traffic, that they can take their own time to turn a rail : it would indeed be better to renounce this property, than to purchase it at this price.

A rail requiring these angle-iron chairs, when compared with the inverted ⊤ rail, presents a complication, of a more or less doubtful character. It is generally admitted that both kinds of rails, the double-headed, and the inverted ⊤ should have the same weight; the cost of first laying is therefore burthened with the expense arising from the intermediate angle irons, besides the additional one of the fish-plates at the joints, all to retain the property of turning the rail; an operation which is practicable no doubt, as far as the rail itself is concerned, but is at the same time delicate, and complicated.

The pecuniary advantage is in fact very doubtful; even while attributing to the turned rail a higher value, than is actually the case, and in pushing economy to its utmost limits in the accessories, which the double-headed rail requires. It is but a poor arrangement to obtain by the assistance of intermediate aids, that stability which is required by the rail; and which it could so easily possess in itself, by a simple change of shape. The Vignoles rail, with the ordinary fish-plate at the joint, combines, more than any other system, economy in first cost, security, and simplicity of maintenance.

The angle-iron fish-plate, but applied to the inverted ⊤ rail, is also found in that collection of all the different systems, which the Bavarian lines present. The two fish-plates are tied together by four bolts, and fastened to the sleeper by three spikes; two on the outside and one on the inside, as on the sections from Munich to Rosenheim, and from Rosenheim to Küfstein. It is difficult to explain this experiment, otherwise than from a wish to condemn nothing *à priori*; and therefore to make trial of all.

95. *Fourth method. Fish-plate chairs.* — The fish-plate chair in shape is only a very long fish-plate, strengthened by a strong sole, as shown in figures 12 to 14, Pl. VI; but it acts in quite a different manner, such as to altogether exclude the joint being placed unsupported. The chief object of the lower limb is not to diminish the disproportion, which exists between the section of the fish-plate, properly so called, and that of the rail; but to reduce the strain, to which the bolts would be submitted, in consequence of the supposed excessive inclination of the bearing surface of the head, whether real or not, this result is obtained by placing the fish-plate on a support, thus opposing to

the thrust the friction of the bottom of the chair against the sleeper, and even the resistance of the spikes, if required.

In this arrangement it is generally sought to reduce the strain on the bearings of the fish-plate, and consequently the pressure itself. As the bottom extends beneath the rail, and is supposed to be in contact with it, the weight ought to be shared between the upper bearings, and the bottoms of the chairs; and as the latter are horizontal, the weight they support causes no thrust. In some cases the rail has not been allowed to rest on the bottom of the chair, and a certain amount of play has been purposely left between them (Pl. VI, fig. 5); the strain on the bolts is in this way however relieved only from the friction of the bottom of the chairs on the sleepers, and the cheeks of the fish-plate chairs are burdened with all the weight, which it seems preferable rather to relieve them from.

If the fish-plate chair exactly embraces the rail, without allowing any play, the distribution of the strain does certainly take place, if it is only by the compression and vertical deflection of the cheeks, but in so very variable a manner, as to be unable to be exactly estimated; so that a basis is wanting to determine the proportions of its elements; with the fish-plate proper the duty of each is however very clearly defined. The fish-plate chair is besides the dearer of the two.

It is used on the Central of Italy Railway (Pl. VI, fig. 1 to 4), from Bologna to Pistoia; and in France on four of the main lines, the Eastern, the Paris and Mediterranean (fig. 32 and 36), the Orleans, and the Western (fig. 5 to 9); on the two first named lines it is applied to both symmetrical, and unsymmetrical double-headed rails, on the two latter to the symmetrical only. The length of each cheek is 1'·2" on the three first mentioned lines, and 1'.4" on the last; they are fastened together by four bolts, and sometimes, though erroneously, by three only (fig. 33 to 35), from $\frac{5}{8}$" to $\frac{3}{4}$" in diameter; and to the sleeper by three spikes, or screws, two outside, and one inside. As the inclination is given to the rail by the slope in the bearing surface of the sleeper, the two cheeks are alike; each one having three holes, when, as on the Western line, the screws are inserted in the horizontal members, instead of merely resting on their edges; in this case the intermediate hole only on the inside, and the two end ones on the outside, are used.

With the fish-plate chair, as with the inverted ⊤ rail, screws appear preferable to spikes, which are very difficult of extraction (59, 60). It is more convenient to place the nuts on the inside, as with fish-plates, and for the same reasons (81); sometimes however, as for example on the Bourbonnais line, it is arranged to place them outside, so that they may not interfere with

the flanges of the wheels, when the tires become worn; this injunction is not however strictly adhered to, for between Nevers and Saint-Germain-des-Fossés, they are placed on either side indifferently.

No doubt, when the form of the rail is such as to preclude the use of the fish-plate proper, the next best arrangement is the fish-plate chair; but experience proves, as has been seen (82), that the former might be applied with all security to rails, having the upper bearing surface much more inclined, than is generally supposed to be possible; that it is not incompatible with a proper distribution, in other respects, of the metal throughout the section of the rail; and that, except in the case of a rail already laid, which is decidedly too sharp to give a good bearing, no reason can be seen, why the angle-iron fish-plate should be preferred to the simple one for the double-headed rail, and still less for the inverted ⊤ rail; which is however to be found on the Brunswick line, but this is a solitary instance. With the unequal headed rail, the shape is sometimes so very erroneous, or in other terms, the disproportion of the two heads is sometimes so very exaggerated, that the lower bearing of the ordinary fish-plate would be reduced almost to nothing; such is the case with the rail already quoted, 57lbs to the yard, on the line from Rome to Naples. With sections of this description, the fish-plate chair may be preferable to the ordinary fish-plate; but it would be infinitely better, to adopt a type of rail properly suited to ordinary fish-plates.

96. Among the attempts, having or their object, to effect both the suppression of chairs, and to cause continuity at the joints, may be quoted one out of a number of projects conceived by Mr Adam, and being in some sort a consequence of the method applied in Westphalia; the rail is supported at the sides by two blocks of wood bolted together through the rail by a single bolt, which thus form a base for it to be firmly bolted to the sleeper, into which its lower member is set up to about half of its depth; this has the advantage of diminishing the tendency of the rail to overturn, and more particularly of relieving the spikes from any transverse strain.

97. *Method proposed by Mr Barberot.* — Now-a-days one cannot certainly on railways allow any important duty to devolve upon pieces of wood of small section, which are liable to split and wear away all the more rapidly, in proportion as their exposed surface relatively is larger; consequently experience has not proved favourable to an ingenious arrangement invented by a French engineer, Mr Barberot (Pl. VI, fig. 37 and 38). The rail having its lower head set in a groove was supported by two short wooden stop-blocks *c*, *c*, butting against the sides, formed by the large wide notch made

in the sleeper; it was all fastened together by means of a wooden screw v, v, passing at right angles through each of the wooden stop-blocks, which it pressed upon by the aid of an iron plate p.

The essential conditions thus appeared to be satisfied; no chair is required, no wedges, all damage to the rail is done away with, even at the joint, and consequently the facility for turning the double-headed rail very much increased; the absence of rebound is ensured by broad lateral plates which press at the same time upon both rails at the joint; whilst any further indentation of the rail into the sleeper is prevented, despite the smallness of the surface of contact, in consequence of the perfect adhesion of the wood and the iron, as they are constantly kept one against the other; all loosening of the fastenings is abolished, as the upright stop-blocks which, unlike the wedge, having its fibres parallel to the rail, have them in the contrary direction, afford a grip which is not influenced by the variation of the temperature and the humidity of the atmosphere; lastly concussions, and lateral thrust are borne by the short stop-blocks, which act in the direction of their length, and with but little reaction upon the screws, the only duty of which is to hold by their tension the rail down exactly on the sleeper.

Such are, at least in appearance, the advantages, which it is only natural to concede to this system, and which in fact seemed at first to be confirmed by applications, made in France on the Eastern, Northern, and Western Railways; but later on its defects began to be felt, more especially the loosening of the joints.

The only effectual method of suppressing the tendency, to the up and down motion, of the ends of the rails is to suppress the cause itself; by establishing continuity between them, as do the fish-plates. As soon as the rail end can detach itself from the sleeper, be it ever so little, the mischief makes rapid progress; in the first place, because the vibratory motion of the rail, at first very weak, loosens the screws, and increases it; and in the next, because the rail, burying itself gradually in the sleeper, in doing so augments the amount of play. No amount of maintenance is able, especially if the speed be great, to prevent these effects, which possibly might have been diminished by substituting bolts and nuts, for screws.

Moreover, even if experience had proved altogether favourable to the system, its application should have been always confined to the double-headed rail; as there cannot be any reasons for extending it, as has been done on the line from Beuzeville to Fecamp, to a rail, which, like the Vignoles rail, has sufficient stability in itself. At present therefore, in the face of the established fact, that the action of the stop-blocks, tightened by the screws, cannot in any manner be compared to that of fish-plates, it is only at the intermediate sup-

ports of the double-headed rail, that the idea of Mr Barberot can be made use of; and moreover even then, it might be prudent to use it only on lines where slow speed is employed. However looking at the progress the inverted ⊤ rail has made, the chances of fresh applications of the system appear very small; the more so from the tendency there is rather to exclude wood completely from railways, than to increase its share in their construction.

98. If the very low rail, used in America, by reason of its flexibility, adapts itself to the generally defective conditions of the sleepers, of the ballast, of the maintenance, and of the method of constructing their rolling stock, it has on the contrary the very grave defect to be almost totally unsuited for fish-plates; for want of space to fit them into. Mr Holley thinks this method of fastening, with bolts and keys, tried since the year 1843 by Mr H. Barr of New-castle, Delaware, must needs be soon abandoned; for it becomes absolutely impossible to use fish-plates, if to the very low total height of the rail is added, as in the pear-headed rail (Pl. VI, fig. 10, 11, 12), a lengthened upper member, reducing the body of the rail to nearly nothing.

Thus the fact is explained, that recourse is had to expedients in America, which have rarely in Europe been made use of, since the application of fish-plates : a joint-plate, doubled over at each side, into which fit the edges of the foot of both rails, is the means most in use; it does not suppress the up and down movement, or the rebound, though it diminishes them : besides nothing proves better the smallness of the advantage gained, than the great length these plates are sometimes made, in some cases such as to reach both sleepers on either side of the joint; though they are not far apart it is true.

99. It is the imperfection of the joints, which appears to have suggested in the United States the rails called, " continuous rails ", and which were tried under various shapes ; Pl. V, fig. 32, shows one of the rails of this description, formed of two cheeks, *f*, *f*, fastened at each joint by three bolts, and of a head, *t*, griped between the jaws of the cheeks. In this form the rail presents an example of an arrangement often used in America and now being tried, as will be seen later on, in Germany; its object being to subject to the action of the wheels a separate piece, which may be replaced independently of the rest : it is hardly necessary to say, that the joints of each of the three parts occur at different points. Besides their complication, the capital fault of all methods of this kind is, that, in place of a single solid, they substitute a combination of distinct pieces, imperfectly connected together, which deflect simply by

slipping one over the other; and which offer but a small resistance, in proportion to their section.

The idea of rendering removable that part, which is the only one at all subject to wear, and thus ensuring to the remainder of the compound body a durability, in some sort, indefinite, is certainly a specious one; but it appears very difficult of realisation, without sacrificing the primary condition of simplicity; and, taking every thing into account, that of economy likewise.

§ VII. — The strains on the metal in the Fish-Plates and in their Bolts.

100. 1° *Fish-plates.* — With fish-plates, which render curves continuous, the end spans of the rail are in the same condition exteriorly, as the others; and equality between the maximum strains developed in the rails, and in the fish-plates, would necessitate $\frac{a'}{a} = \frac{I'V}{IV'}$: I being the moment of inertia of the section of the rail; I' that of the two fish-plates; V and V', the respective half heights. Whilst however the expression $\frac{I'V}{IV'}$, is always inferior to 0·25; the ratio $\frac{a'}{a}$, with the supported joint, often reaches, and even surpasses 0·8; on the central of Switzerland for example, where rails of three different lengths have been employed, $\frac{a'}{a} = 0{\cdot}767$, 0·823, and 0·878. On a part of the "Main-Neckar" line, and on the Baden railway, the sleepers are all equidistant; in this case it was supposed, that the width of the joint sleeper would in reality reduce the joint span.

In general but little attention has been paid to the strains developed in the fish-plates, especially when the joint is supported; their section appears to be strictly sufficient, but this is no reason for neglecting any simple means of improving the resistance of the joint, and thus diminishing the disproportion between the strains developed in the rail, and in the fish-plate.

With the unsupported joint this is generally a little better. On the Northern of France, for example, it is;

For the rail $\frac{I}{V} = 0.000{,}142{,}500.$

For the fish-plates $\frac{I'}{V'} = 0.000{,}032{,}500.$

Whence $\frac{a'}{a} = 0.228.$

Whilst in fact $a = 3'{\cdot}0''$, $a' = 2'{\cdot}0''$; and therefore, $\frac{a'}{a} = 0{\cdot}67$.

A ratio nearly equal to that, which had been adopted for the line when without fish-plates, viz, $a = 3'{\cdot}9''$, $a' = 2'{\cdot}7''$; $\frac{a'}{a} = 0{\cdot}69$.

The disproportion in the strain is therefore much less, than on many lines using the Vignoles rail, where the joints are supported; but as the consequences might be more serious, perhaps it is exaggerated. To counterbalance it in part, the section of the fish-plate should be somewhat increased.

It is true, that they are made of a better quality of iron, and particularly one that is less brittle, than the rail; but however, while avoiding breakage, care must be taken not to use too soft an iron, which by allowing the fish-plates themselves to become bent, would soon produce a permanent set at the joint. The bars used for fish-plates are at best submitted only to summary tests; the examination being confined more to the form, than to the quality of the iron. The specifications of the Eastern of France line stipulate simply, that " the bars should present a clean section when broken, fibrous, or close grained "; and it is added " special tests shall be made to ascertain the quality of the iron. " On the Orleans Railway, on the contrary, much attention is paid to the quality; and the specification prescribes certain precise, and severe tests, which it is useful to make known.

Art. 5. The bars, intended to be used in the manufacture of fish-plates, shall be carefully arranged at the works, in the order of their manufacture extending over one or more days. The agents appointed to inspect them will choose in each series a certain number of bars, at most 1 per cent, which shall be submitted to the following tests.

First test.— Two bars together, laid down on two supports 3'·7" apart, are expected to support during five minutes, at the centre of the span between the supports, and without there remaining any perceptible set afterwards, a load sufficient to cause a strain of 13 tons per square inch of the weakest section.

Second test. — The same bars, in the same position, shall support during five minutes, a weight producing on the weakest section a maximum tension of 33 tons per square inch; the weight will then be increased until it breaks.

Third test. — Each half of the broken bars, arranged in pairs, and placed on two supports, 3'·7" apart, shall sustain without breaking the blow of a 6cwt monkey, falling a height of 3'·3" on to the bars, in the middle of the span between the supports.

In this last case the two supports shall be of cast iron; resting by means of an oaken frame, on a block of masonry, of at least 3'·3", in thickness.

Fourth proof.— Finally special tests shall be made to ascertain, whether the iron is properly welded in the interior of the bars.

If, after these rigorous tests previous to their being received, it is later on discovered that the fish-plates are too weak, relatively to the rails, the first thing would be to relieve them somewhat at the expense of the latter, taking advantage of the slight margin often remaining, by bringing the joint sleepers a little nearer together.

101. 2nd. *Bolts* (*). Theoretically the tension of the bolts is null, with fish-plates having a rectangular section, or even with the bearing surface at such an inclination, that the horizontal thrust of the rails is kept in equilibrium by the friction due to the load.

1° *The unsupported joint* (Pl. VIII, fig. 2 and 3).

As the middle of the fish-plate occupies the centre of span a', the strain is greatest when P is applied at this point; π being the resultant of the vertical pressures, exercised at either extremity, by the rail on the upper and lower bearing surfaces of the fish-plate, supposed at first to be horizontal; d the distance between the point of application of the forces $\pi, -\pi$; I' the total moment of inertia of the two fish-plates; ρ' their radius of curvature at M; then, we have $\frac{EI'}{\rho'}=2\pi d$. If the span a' is supposed to be horizontally fixed at the two ends, its points of contrary flexure are situate at one quarter, and at three quarters, of its length: in this section there is but one shearing strain $\frac{P}{2}$; therefore $\frac{EI'}{\rho'}=\frac{Pa'}{8}$, and consequently $\pi=\frac{Pa'}{16d}$.

The reaction between the rail and the fish-plate, per unit of surface, is at its maximum at M for the upper bearing surface, and at H for the lower one. As the fish-plate is supposed to be fixed in its place without any play, the

(*) These strains have sometimes been miscalculated; thus in an article on fish-plates having a lower projection, which were tried on the Bourbonnais line (" Annales des mines, " vol. XIV, page 299), Mr Desbrière, a late pupil of the Polytechnic and of the School of Mines, proposed to calculate the strain on the bolts of ordinary fish-plates on one span only, thereby omitting the reaction of those, on either side of the joint one.

According to Mr Desbrière the two vertical components, Q and R, of the pressures exercised by each rail on the upper, and lower surfaces of the corresponding half of the fish-plate are unequal; the former being the greater. The equality of these two forces is evident however, since the entire fish-plate is in equilibrium vertically, under the reaction of the rails only; and, as the half on each side of its centre is like to the other, and is similarly under the action of a load applied at the centre of the span, under whatever circumstances the span be placed upon its supports, the following equality must exist $2R=2Q$.

pressures are distributed throughout the whole length of each bearing; and admitting that the pressures are proportional to the strains, the sum of the reaction will be measured for each bearing by the area of the triangle of impression $\alpha\beta\gamma, \delta\varepsilon\zeta$; the resultants π will therefore be at $\frac{1}{3}$ and $\frac{2}{3}$ of the half length, l, of the fish-plate, counting from the centre; whence $d = \frac{1}{3}\,l$, and $\pi = \frac{3}{16}\frac{Pa'}{l}$.

There is already therefore, as regards the intensity of reaction, a great advantage in employing long fish-plates.

Let $a' = 2'\cdot0''$; $l = 9''$; then $\pi = 0\cdot51$ P : and when P $= 6^{\text{tons}}.8^{\text{cwt}}$; then $\pi = 3^{\text{tons}}.5^{\text{cwt}}$.

As the faces of the bearing surface form with the vertical an angle α, the resultant 2π, following the direction of the axis of the rail, gives on each of them a component at right angles, $t = 2\pi\frac{\cos\alpha}{\sin 2\alpha} = \frac{\pi}{\sin\alpha}$; which itself gives a vertical component π, and a horizontal one $\frac{\pi}{\text{tang}\,\alpha}$ (Pl. VIII, fig. 3).

f being the coefficient of friction, it introduces a horizontal component, $-f\frac{\pi}{\sin\alpha}\sin\alpha = -f\pi$. The force producing the tension τ of each bolt is therefore, $\pi\left(\frac{\text{tang}}{1} - f\right)$; and h being the mean height of the fish-plate, its equilibrium of rotation round the point O, is $\tau\frac{h}{2} = \pi\left(\frac{1}{\text{tang}\,\alpha} - f\right)h$; whence $\tau = 2\pi\left(\frac{1}{\text{tang}\,\alpha} - f\right) = \frac{3}{8}\frac{Pa'}{l}\left(\frac{1}{\text{tang}\,\alpha} - f\right)$, to which tensile strain must be added that previously existing, due to the screwing.

For the symmetrical rail of the Northern of France Railway, tang $\alpha = 1.14$ nearly, $a' = 2'\cdot0''$; $l = 9''$; whence allowing, that $f = 0\cdot2$, and that $\tau = 0\cdot680$ P $= 4^{\text{tons}}.7^{\text{cwt}}$, when P $= 6^{\text{tons}}.8^{\text{cwt}}$. The bolts being $\frac{3}{4}''$ in diameter and having a section of $\frac{7}{16}$ of a square inch, the strain per square inch would be $9^{\text{tons}}.12^{\text{cwt}}$.

The intermediate bolts should not be too near to the centre of the fish-plate, to avoid weakening it in that part; it is better however, that they should be sufficiently near to the resultants of the thrust of the rail, towards the extremities, as well as in the centre.

In the greater number of rails with unequal heads, and in many also of the inverted T shape, the upper and lower bearings have, as has already been

stated (83), different inclinations; the two thrusts, and consequently the tension of the two bolts, the end and intermediate one, are then also different; naturally the angle of the bearings of the foot is the largest, and therefore with the unsupported joint, the tension of the end bolts is a little less, than that of the intermediate ones.

102. 2°. *Supported joints.* — In this instance the moment of rupture in the fish-plate is greatest, when the load reaches one third of the length of the bearing (68); and the greatest strain, in the middle of the fish-plates, is, $R = \frac{4}{27} \frac{V'Pa'}{I'} = \frac{EV'}{\rho'}$.

Whence the moment of rupture is $\frac{EI'}{\rho'} = \frac{4}{27} Pa'$; and therefore $\frac{4}{27} Pa' = 2\pi d = \frac{2}{3} \pi l$; whence $\pi = \frac{6}{27} \frac{Pa'}{l}$.

Therefore the tension between the bolts is as $\frac{3}{16} : \frac{6}{27}$, or as 1 is to 1.185, according as the joint is unsupported, or on a sleeper; or in other words, the length of the bearings should be in inverse ratio to each other, in order that the bolts may be equally strained.

Let us merely mention, that when the lower bearing has a larger angle, than the upper one, the end bolt is the most strained; the reverse of what takes place, when the joint is unsupported.

103. *Maximum pressure, per unit of surface, on the rail and on the fish-plate.* The sum of the normal reactions between the rail and the fish-plate at each bearing, is

$$\frac{\pi}{\sin \alpha} = \frac{6}{27} \frac{Pa}{l \sin \alpha};$$

e being the length of the bearing, R the maximum value of the pressure per unit of surface. These reactions are also expressed by $\frac{Rel}{2}$; whence $R = \frac{12}{27} \frac{Pa'}{el^2 \sin \alpha}$.

On the Eastern of France Railway, for example, the inverted ⊤ rail has the following dimensions for the head, $\alpha = 45°$, $l = 9''$, $e = \frac{1}{8}''$, $a' = 2'{\cdot}7''$; whence $R = 821P$, and since $P = 6$ tons $7\frac{3}{4}$ cwts, $R = 5252$ tons 13 cwt, *i.e.* 3 tons 3 cwt per square inch; a very moderate load, but which is soon exceeded, if, through the joints being defective or the bolts getting loose, the strains are

concentrated on the shorter lengths; and moreover are the cause of repeated concussions.

104. Calculation gives very high values for the amount of strain on the fish-plates, but which it seems at first difficult to reconcile with the few breakages which occur among them; and the more so, as has been already observed on the subject of rails (69), from the fact, that many causes, which add thereto, have been neglected. But on the other hand the basis of the calculation, the supposition that the whole load is concentrated on a single element of the rail, tends of itself materially to exaggerate the effect; the load is in reality distributed over a considerable extent of rail, especially between those sleepers, where the joints occur, and at which point they naturally deflect most. Some engineers, to increase the resistance of the fish-plates when unsupported, have added to its breadth downwards; bending it over the lower head, and sometimes even turning it under; to this double-bend a vertical support has sometimes been added. The former plan has been adopted by Mr Wilson for the self-supporting joints of the Vignoles rails on the Indian Branch Railway (188). The latter method, already employed in the Unites States (Pl.VI, fig. 12, 13, 14), has been tried with the double-headed rail on the line from Paris to Lyons (Bourbonnais). The section of the fish-plate is by this means undoubtedly much increased, but experience proves, that this augmentation is unnecessary; for fracture is very rare with ordinary fish-plates, even without the necessity of reducing the length of the joint-span to the extent of rendering packing the sleepers a difficult operation. Besides, were it considered necessary to increase the section of the fish-plate to a certain extent, it would be preferable to add to its thickness a little, and to preserve its form, rather than to concentrate the additional metal at the base; for by this the neutral axis would be caused to descend; so that the bolt-holes, which cannot be moved to a similar extent, would sever fibres, which, when the plate deflects are subjected to considerable longitudinal strains; thus enfeebling the upper member, already the weakest, except in whatever may arise from this cause.

§ VIII. — Longitudinal displacement of rails.

105. *Its causes.*

The wheels of the carriages have not only a tendency to displace the rails by transverse slipping, and so to increase the width of the line, but also to displace them longitudinally; both of which tendencies must be overcome by the medium of the spikes.

If we remark a train moving at a uniform rate along a straight piece of level, we shall see, that the two lines of rail passed over by the train are acted on in the direction of their length by two horizontal forces in contrary directions; 1st by the tangential pressure of the driving wheels; 2nd by the tangential pressure of the other, or simply supporting, wheels, both of the engine and of the carriages; a force which is equal to the reaction, that causes their rotation. The former tends to press backwards the rail, to which it is applied; the latter urges forward those on which it acts. These two forces are nearly equal, but the first exceeds the second by the resistance of the air acting directly on the engine; and while one of them is concentrated on a single rail, or on two at the most, the other is distributed over the whole length of the train in motion.

The first named force cannot however in general of itself alone cause longitudinal dragging of the rails, to effect this the tangential pressure of the wheels upon the rail must exceed the friction of the latter on its supports; even if the tangential pressure, owing to the wheels being locked, reaches its limit, the amount of friction would scarcely equal that of the rail on its supports; where the coefficient is at least as great, and due to the same load, indeed if not to a rather greater one, since there is in addition the weight of the rail. To the friction arising from the weight of the train, there is to be added that, which is caused, according to the system of rail laid down, either by the wedges, or by the pressure of the heads of the spikes or screws; so that we must conclude, that the rails cannot slip on their supports under the action of the tires of the wheels, even when the break is applied; nor even from that of the driving wheels, which, when the engine is reversed, act as if the break were on, and have then a tendency like the other wheels to urge the rails in the same direction as the train. Still less can the rails, while dragging, carry the sleepers along with them; for the nature of the friction of the sleepers upon the ballast, and of the ballast itself is all the more favourable to their stability; to the action of this friction must also be added the pressure of the ballast, which the sleepers would have to drive bodily before them.

These conditions might certainly be modified by looseness among the particles of the ballast, provided their form permitted them to roll, instead of slipping one over the other; but this would tend to facilitate the movement of the sleepers, and experience in general proves, that this does not often take place.

The displacement of the rails is, from the same cause, impossible on an ordinary incline, and with the amount of inclination generally given to the rail, which is always considerably less, than the angle of friction of the different

elements of the permanent way upon each other; since the maximum value of the tangential reaction of the wheels, or in other words their friction, at most but reaches that of the rail on its supports; and to this the other resistances have still to be added.

In curves a special cause of dragging arises; if the rolling stock is too stiff, or the distance between the axles too great for the radius of the curve, the flange of the front wheel is kept constantly jammed against the outside rail, and that of the hind wheel against the inside rail. Again the same effect may be caused by a rate of speed differing much from that, upon which the cant was calculated (**174**); if too great the flanges of the wheels are pressed against the outside rail, when too little they hang back upon the inside one.

In fact, unless some special precaution is taken to counteract this longitudinal dragging, the rails will move in the same direction as the train, in curves, as well as in straights; indeed it is often in the latter, that the movement is most marked, where, as well as in curves, its two main causes are, the slight rebound which is formed at the joints in front of the wheels, and the deflection of the rails. For the wheels exercise upon the ends of the rails, and also upon the slight inclined plane, which the deflection of the spans between the sleepers continually causes in front of them, a pressure in proportion to the speed of the train. The effect of the deflection is in reality very slight; for, even if it produces, in the case of the wheel ascending the slight incline, a horizontal resultant urging the rail forward, it also sets in action, on the part of the support, a contrary reaction; so that this element may be neglected, when the nature of the ballast, and the size of the sleepers is such, as to allow them to be considered as fixed, which is usually the case.

The influence exercised by the rate of speed explains the comparatively slight displacement of the rails in curves of small radius; here this rate is much diminished, and this reduction generally more than compensates for the wearing action of the flanges. This same cause explains also the small amount of dragging on very steep inclines, while it is very decided on those of more moderate inclination. For in the former case precautions are taken to effect the descent at a gentle pace, while in the latter the drivers, knowing that they can descend rapidly without danger, without any increased consumption of fuel, avail themselves of it to make up for lost time; even at equal speeds the rails yield more easily to the action of the wheels on an incline, than on a level.

106. *Means of counteracting the tendency to dragging.* — As this movement is due chiefly to want of level in the joint, the fish-plate, which has consider-

ably diminished this last inconvenience, ought likewise to reduce the former evil. Experience, in fact, has proved, that, since the addition of fish-plates, and since the permanent way has been better maintained, this tendency to dragging has been considerably diminished, although the speed generally has been augmented.

It was principally to counteract the longitudinal dragging of the rails, for which purpose mere keying up of the wedges proved quite ineffectual, that it was resolved to use fish-plates on the Etampes incline of the Orleans Railway, which is of 1 in 120.

The influence of the fish-plate joint is not confined only to diminishing the cause of the mischief; it acts also very effectually in restraining any motion on the part of the rail, which, through it, can only yield to the pressure of the wheels, after having surmounted a fresh obstacle, the friction due to the tension of the bolts.

This kind of joint is still not perfect, and leaves something farther to be desired, in this respect. This was soon observed on lines using a high rate of speed, and where it was supposed, that the fish-plate would have been sufficient to counteract the longitudinal displacement of the rail, for instance on the incline from Chantilly to Creil on the Northern of France line, and on the Velletri incline on the railway from Rome to Naples; similarly on the Madrid to Alicante line, where no precaution was taken to stop the movement in the Vignoles rail, which had been substituted for the Bridge rail after a very short trial.

107. With the Vignoles rail it is extremely easy to counteract this tendency; it suffices to place one or more stops against the foot of the rail so that it cannot drag without at the same time displacing several sleepers. It naturally follows, that the complete connexion here referred to, is established by means of the fastenings of the rail to the sleepers; this may be effected by forming in the foot of the rail two, or more holes, opposite to each other, for the body of the spikes or screws to fit into (Pl. IV, fig. 37; Pl. V, fig. 19).

Here again is one of the proofs, which we meet with at every step, of the inferiority of the chair rail, compared to the inverted ⊤. With the former, to counteract this longitudinal movement, a complete connexion between it and its supports, which are dependent upon such an imperfect means as the wedge for being made tight, can only be obtained by the addition of a special piece. Hence those in favour of the fish-plate chair claim for it the advantage, which it certainly possesses, of aiding this connexion; for the broad base of the fish-plate chair can, like the inverted ⊤ rail, be made with stop-holes. This is a real advantage, which the angle-iron fish-plate also shares; if however it be

made a reason for preferring the fish-plate chair to the ordinary fish-plate, as a mode of fastening for the double-headed rail, then it becomes a serious objection to this rail, as excluding the simplest, the most effective, and the most economical method of ensuring complete connexion at the joint. This is rarely done however, for it is the ordinary fish-plate which is certainly most frequently used even on chair-rail lines; where, by using a good firm-holding fish-plate, and thus almost entirely doing away with any jumping tendency, this longitudinal dragging is but slight, though it is still more decided, than with the Vignoles rail, as the maintenance will soon show. So that in fact, whatever method is adopted in making the joints, the inferiority of the chair rail is apparent.

With the inverted ⊤ rail the hindrance to displacement is the spike fixed in the notch of the foot, which acts directly on the rail; while with the fish-plate chair it is only by the medium of the friction due to the tension of the bolts; and, if this is not sufficient, by the direct action of the bolts, which then act transversely.

If the double-headed rail has at the joints neither fish-plates, nor fish-plate chairs, the dragging may become excessive, especially in dry weather; in consequence of the amount of rebound, and of the freedom of the rail to move, confined only by the wedges. In consequence of this it has been found necessary on the Western of France to add a stop bolt A (Pl. V, fig. 37), which presses against the inner cheek of an intermediate chair. The Eastern of France railway has recently had recourse to the same expedient on the line from Rheims to Givet, which is only partially supplied with fish-plate chairs.

It is nearly always sufficient, if the fish-plating is well done, to effect a close connexion between each rail and one of its supports. When the inverted ⊤ rail with joints on the sleepers is used, this connexion may be effected either with one of the end sleepers, or with an intermediate one. Fault is sometimes found with this latter arrangement, which is the most usual, on the ground of its weakening the rail; but, as the fractures do not happen more frequently at the point, where the holes occur, than elsewhere, both positions may be regarded as alike. On lines where no stop-check had been previously applied, as for example, with the inverted ⊤ rail on the Northern of France line, the end position is naturally adopted. It sufficed in this case without altering the spikes to make two small notches in the foot of each rail at the lower end, and to set in them two wedges (Pl. V, fig. 12, 13), against which the rail presses; a single wedge can be placed at first, and a second added if the first gives a little.

108. *Steep inclines cause no effect.*

It was much feared at first that a longitudinal dragging of the rails would take place on the steep inclines of the Semering line; to counteract this it was thought necessary to connect the cross sleepers by means of strong longitudinal balks placed underneath; this was applied to the ascending line as well as to the descending one, but experience has rendered questionable the utility of this arrangement, which was very troublesome for the maintenance. At the present time the longitudinal balks have been done away with, and the rails, notched at the ends, now have but little motion. This result is simple in itself, for the speed was much reduced on the inclines of 1 in 40 of this remarkable line; the sharpness of the curves, of 9 chains in radius (*), and the rigidity of the locomotives may have caused some uneasiness, but their tendency towards this movement of the rails, stopped at one end, and at an intermediate point, is naturally diminished by the necessary reduction in the speed.

On the Hauenstein incline, of 1 in 37, on the Central of Switzerland railway, this movement is almost null, or hardly appreciable; on the line from Steïerdorf to Orawitza, in the Banat, notwithstanding its numerous curves of $5\frac{1}{2}$ chains radius; and also from Busalla to Pontedecimo, on the line from Turin to Genoa, with an incline of 1 in 28, the same is the case; the latter is a chair-rail line using ordinary fish-plates; the stability of the rails being chiefly due to the speed, which is diminished in proportion to the steepness of the incline, and to the large radius of the curves, which is never less than 20 chains.

On the Belgian Luxemburg line notches were made at all the sleepers; spikes are used at the intermediate ones and screws at the joints, which are provided with plates, although the sleepers are of oak (Pl. IV, fig. 21). In consequence of the numerous inclines on this line (35), it was thought necessary thus to connect the rail closely with all its supports; the preceding examples, however, prove that this precaution is more than necessary.

109. Though experience has proved, that sleepers of hard wood, such as oak, beech, etc., do not require to be protected with joint-plates, some engineers have thought it prudent nevertheless to retain them, to resist more effectually the longitudinal displacement of the rails; as the plate holes determine exactly the position of the spikes or screws, and necessitate their insertion in the notches of the rail. The addition of an intermediate plate was even recommended for the same reason, when the rail was notched at that point; in this

(*) These curves will be reduced to a minimum radius of ten chains (110 klaft), except that of Eichberg.

case there may be some reason for it; for the notches being necessarily of but slight depth, $\frac{1}{4}''$, in order not to weaken the rails, careless plate layers might not drive home the spikes sufficiently; at the end of the rail, however, there is nothing to limit the depth of the notch, and it is always certain that the stop-wedge, even carelessly driven, will fasten it more than is necessary. To place the stop-wedges at the end of the rail is quite as efficacious, as at an intermediate point; and as two wedges are much more economical than one joint-plate, or even than an intermediate plate, these additions are quite useless, except for a different reason, as in the case alluded to farther on (181), and in curves of small radius.

After having been for a number of years almost unquestioned in Germany, the utility of the joint-plate is now disputed, and even absolutely denied: in the inquiry made upon the subject at the Dresden meeting, the lines from Berlin to Hamburg, from Lübeck to Buchen, the Hanoverian, Westphalian, and Brunswick lines pronounced formally in favour of its abandonment. In the case of the line from Lübeck to Buchen, this opinion is based upon the experience of thirteen years working of the line, during which long period, it is asserted that, thanks to a good system of fish-plates, the rails do not penetrate the sleepers, even when made of fir.

CHAPTER IV.

RAILS ON LONGITUDINAL SLEEPERS.

§ I. — Discussion of the principle.

110. One objection to the double-headed rail is, that the sides of the upper, and of the lower member are unsupported; should the inclination of the rail be slightly altered, or the shape of the tires become worn, the sides of the head, which carry the load, at once lose their form, and give way; it would therefore under these circumstances, be a considerable advantage to substitute in place of the double ⊤, the type of this kind of rail, the hollow rectangle which is its theoretical equivalent.

The idea of the bridge-rail comes from this form, and is but a modification of the inverted ⊤ rail, by splitting in two the web and the foot up the middle, and placing each half vertically under the outside of the head of the rail.

The stability of rotation of the rail is at the same time increased, but it is a mere nominal advantage; for a considerable breadth of bearing is a disadvantage for a rail which only admits of longitudinal supports of a limited breadth; the rail, in fact, has already so much tendency to get out of shape by opening out, that to support it only at intervals, even though they be but small, is not sufficient to counteract this tendency.

The absolute necessity of a continuous support for the bridge-rail is in itself so evident, that it may appear superfluous to quote the results of experience upon the subject. The system has, however, been several times tried; in Ireland, where the weight of the rail was as much as 90 $\frac{1}{2}$ lbs per yard; in Germany on the lines from Magdeburg to Berlin; from Magdeburg to Leipsic. (Pl. II, fig. 29); on the Lower Silesia railway, and in the Duchy of Baden.

The rail of the Berlin to Magdeburg line weighed 42 lbs per yard; the sleepers were 3'·0" apart. Tested under the lever press, permanent set took place under a pressure of 1 ton, 18 $\frac{1}{2}$ cwt.; it broke under pressures varying from 5 tons 19 cwt., to 7 tons 14 $\frac{1}{2}$ cwt. The load on each driving wheel on this line was 4 tons 3 $\frac{3}{4}$ cwt.; it is not therefore astonishing that this permanent way soon showed itself defective; the rail was too light, and its form increased its weakness.

As continuous bearing is a necessary element of the bridge-rail, this form cannot be compared with other rails, if the arrangement of the sleepers be set aside, as with it cross sleepers cannot be used, while the inverted ⊤ rail admits equally of transverse and of longitudinal sleepers; as regards the chair-rail, though nothing prevents the use of longitudinal sleepers, it is evident there would be no gain unless the whole depth of the foot of the chair, were sunk into the sleeper, or it were replaced by an angle-iron fish-plate. The worth of the principle of continuity in the supports is therefore an essential element in estimating the value of the bridge rail.

111. At first sight this principle seems to have some advantages in its favour, for the rails, being subjected successively at every portion of their length to the action of the same forces, ought, as far as possible, to be in the same condition externally throughout their whole length. The break of connexion at the joints, however, prevents this absolute uniformity; for the compressibility of the ballast occasions a certain deflection, varying with each span, according to its position in relation to the joints, unless this break in the continuity is completely compensated; in the case of the rails by arrangements of the nature of fish-plates, and in the longitudinal sleepers by the method of connecting them together, or with the cross ties placed at the joints.

On lines where cross sleepers are used, they are generally 3 feet apart, from centre to centre, and are 8 ft. 2 in., or more in length; the bearing surface with cross sleepers therefore exceeds by nearly 39 per cent that of the two lines of rails, or of their longitudinal supports; this excess amounts to nearly 74 per cent, on the Great Western with its 7 ft. gauge, allowing the same projection of 1′ 8″ outside the rail, which is hardly sufficient. The amount of wood, required for the cross sleepers, is already considerable, and whether this suffices, or not for longitudinal ones, no one would think of increasing it with them; the cross ties, which the longitudinal system requires, do not amount to the difference, even with the narrow gauge, and with the intervals at present in use; so that, as far as economy of wood is in question, the advantage seems to belong rather to the longitudinal system, than to that of cross sleepers. No doubt a continuous bearing allows, "cæteris paribus," some diminution in the weight of the rail; this however is often carried to excess. These considerations may render it at first sight somewhat difficult to explain the universal preference shown to the cross sleeper system; nevertheless it is perfectly clear, that there are good grounds for this preference.

112. In the first place, taking only the prime cost of the wood into consider-

ation, even a considerable reduction in the cube would not necessarily imply a diminution in cost. Regularity of shape, a secondary consideration for cross sleepers, is indispensable for longitudinal ones; which must be straight, and nearly as even as the rail, and free from splits, especially at the edges, where the fastenings are to come; in fact, they must be of picked timber. The workmanship also differs in quality; instead of rough, or imperfectly squared timber, which is easily and quickly prepared by any kind of workman, the balks require to be carefully cut, and planed; it is really carpenter's work. It is probable, that systems of permanent way on longitudinal sleepers have often failed through want of care in the details of the work, but this does not justify their principle: it is one of its drawbacks, that a degree of precision and care, but little in keeping with the nature of the work, is required in its execution, and this is quite done away with in laying cross sleepers.

The increased difficulty of draining the line is also urged against the longitudinal system, and with some reason.

The principal and primary fault however of these sleepers, and which has discouraged the chief supporters of the system, is their instability. For they are, to a certain extent, in an unstable equilibrium; and their tendency to overturn, and to slip laterally, can only be overcome by connexion between the two parallel rails; and which is difficult to effect completely even with aids, that detract from the simplicity of the permanent way, and from the independence of its several elements; a thing so necessary for its proper maintenance.

It may also be argued, that fish-plates can be objected to on the same score, and yet that this has not prevented their general adoption; in this case, however, the advantages are clear and incontestable. This argument would only hold good if the use of longitudinal sleepers dispensed with fish-plates, which is not the case; for fish-plates are just as necessary with longitudinal, as with transverse sleepers; and although they are not applied to the bridge-rail, it is not because they are useless, but that they are inapplicable to this system. We shall return again to this matter.

113. *False idea of a mixed rail.*

The first condition of success for a system is to be consistent in itself, and not to depart from its principles. The advocates of the longitudinal system have always represented it, as a simple variation of a line on transverse sleepers; the only difference being in the mixed nature of the rail, and in the greater interval between the cross ties, than between transverse sleepers, a natural consequence of the greater stiffness of the composite rail, aided by the action of the ballast between the sleepers.

The worst is, there is actually some truth in this way of looking at those lines on longitudinal sleepers, which are best known; that is with the cross ties underneath. The objection is however both a definition and a criticism.

This idea of a mixed rail, half wood, half iron, will hardly bear examination. One can easily understand how the first rails of this fashion, were made with a single flat plate of iron, nailed or screwed on a longitudinal bearer; each of these materials, however, had a distinct function to perform, suited to its nature and form; the sleeper resisted deflection, the iron plate friction, the combination was logical. But the superposition of two solids, each furnishing its own quota of lateral resistance, is correct merely when it is possible, by simple means, to effect a complete union between the two, and thus constitute a whole capable of deflecting together. It is useless to increase the number of fastenings to the detriment of the sleeper, for iron and wood are unsuited for a union of this kind; a change of temperature causes in the system constant extensions and contractions, which loosen the fastenings, and wear out the sleepers; since they act, sometimes in one direction, and sometimes in another. All that can be expected from the fastenings, whether they be spikes, screws, or bolts, is to perform exactly the same function with the longitudinal, as with the cross sleepers, without exacting a connexion, which would soon be destroyed by its own action : each material then deflects independently of the other; a constant series of slipping motions takes place at the surface of contact, which must not only be tolerated, but even assisted; for the more freely it takes place, the less injurious it is.

To this view of the question may be objected a well known example, that of the Great Western; instead of spikes or pegs placed exteriorly to the rail, and pressing only on the edges, without impeding its expansion, Mr Brunel persisted in using wood screws, very close together; and inserted in the foot, without allowing for any play. In Germany this arrangement had been laid aside before the rails were, for the screws got loose, and were knocked out. With bolts and nuts the effect was slower, but the mischief still existed. Can it however be said, that the Great Western permanent way is not a good one? But, if it is good, it is not in consequence of the system, and especially not on account of the mode of fastening, but in spite of it : it is because the longitudinal sleepers are of large dimensions, the rails very heavy, the load on each axle very limited, and very great care is bestowed upon the maintenance, which is probably very expensive. It has besides been mentioned elsewhere, that the screws get loose, not only at the joints, but nearly every where else.

114. If the longitudinal system is so little used in France, it is from the

fact, that it was little thought of at the time, when it was in vogue in England, and in Germany. The chair rail was the only system approved of, at that time in France, which had come into general use; not through conviction of its superiority, but through an equally powerful cause, viz. custom. The longitudinal system of permanent way only came into practice later on, consequent upon, and as one of the forms of, the reaction against the chair rail. But this experiment was as useless, as it was tardy; for it would then have sufficed to glance at the very conclusive results of the experiments previously tried in Germany, in order to know what one might expect of it.

It is especially because continuity in the supports is in itself a specious thing, and because it has been adopted from the first on this score, and tried in many forms, yet always with very moderate success, that we ought to be doubtful of it. The question is not, whether with the longitudinal system a good permanent way may be constructed, or not; indeed this system might be capable, setting expense aside, of a degree of perfection unattainable by the other; but what facts do prove is, that a system of continuous supports is not favourable to economy of maintenance, and to the preservation of the different elements of the permanent way. The example of the Great Western, cited above, is, as I have already stated, only conclusive in a very moderate degree, and this for two reasons; first, that in this case the great breadth of the way affords a special plea in favour of the longitudinal system; and second, that the system was not adopted on this line for its own merits, but as a necessary consequence of the systematic preference given by Mr Brunel to the bridge-rail; a preference which will be discussed later on.

§ II. — Examples.

115. In America, as in Germany, the longitudinal system was the first one used. It was even with a view to this method of application, that the inverted T rail was first adopted, in preference to the double-headed one. The longitudinal system of sleepers has for some time past been universally abandoned on the other side of the Atlantic, though the rail has in all cases been retained. This form of rail, though at first selected solely for its adaptability to the longitudinal system, is now itself preferred for its inherent advantages.

116. The same change has taken place in the Duchy of Baden; but here the question has passed through different phases, sufficiently instructive to make them worth recalling, though they date some time back. If a system has

ever been condemned with a full knowledge, it is in this case, where the result of observation of facts has overcome, both preconceived ideas, and customs of long standing.

The bridge-rail adopted for the first section, from Manheim to Heidelberg, was 6″ broad; it was fixed on longitudinal sleepers 12″ by 6 $\frac{1}{2}$″, with spikes placed outside the foot; the joint was strengthened by a cast iron plate, fastened to the sleeper by spikes, with a projecting head fitting down on the rail. On embankments cross ties were used, only three feet apart, and on the average 6″ by 6″, and 7′.10″ long (*). In cuttings, blocks of red sandstone, 3$\frac{1}{2}$ c.f., in size, and 5 feet apart, were substituted for them; on the level these blocks alternated with cross ties. The longitudinal sleepers were either fixed on the ties, or on the blocks, by oak pins 1″ in diameter.

The cube of timber was very considerable : in embankments it amounted to 9170 cubic feet per mile of single way; 5720 being for the longitudinals, and 3450 for the ties.

On the second section of the line, from Heidelberg to Carlsruhe, the following experience, acquired on the former section, was made use of.

1st. The rapid disarrangement of the joints, the deterioration of the ends of the rails, and the frequent breakage of the cast iron saddles, soon showed the imperfection of this system of joining the rails; to improve it the breadth of the cast saddle-plates was increased, with a greater number of raised edges between which to insert the foot of the rail.

2nd. The stone blocks were given up on account of their inability to resist, in spite of a very careful maintenance, the tendency of the longitudinal sleepers to slip, and overturn.

3rd. The cross ties were made rectangular, those at the joints, were 12″ by 5″; the rest 8″ by 5″; their distance apart was increased, from 3 ft. to 5 ft.

4th. The want of stability in the longitudinals was sought to be remedied by substituting ballast, having greater stability than gravel; viz. a layer of broken stones from 6″ to 8″ in thickness.

When, at a later period an extension was proposed to Offenburg and Haltingen, the question of the fastening of the joints again presented itself; for the modification above mentioned had, but partially answered the expectations of the engineers. The fracture of the plates, especially at their centres, was as frequent, the rebound at the joints as marked, or nearly so, as with the first arrangement; these effects might be partly attributed to the use of heavier engires, but it was necessary to remedy them, whatever the cause.

(*) The line was at this period 5′ 3″ broad, from centre to centre of rail.

For this purpose the cast iron saddles were replaced by wrought iron plates, with raised edges but without any centre. A flat plate, or horizontal cover-joint, was added to each side, covering the outside edge of the rail and the raised rim of the plates, which were on a level with the former; bolts, with a triangular nut below, with claws to it, were substituted for the spikes, to allow of the head being screwed up (Pl. IV, fig. 25, 26, 27); the body of these bolts passed through a notch in the foot of the rail.

When the second line was about to be laid, the form of the rail was again called in question, and declared defective. It had, however, notwithstanding its lightness, 37^{lbs} per yard, given good wear, a circumstance due chiefly to the good quality of the iron, and its careful manufacture; so that it was not the rail itself, or its shape, that could be objected to, but the imperfection of the joints, and which appeared irremediable. The inverted ⊤ rail was then adopted, but solely at that time on account of its fitness for a method of connexion, quite unsuited to the bridge-rail; viz., by means of fish-plates. No other alteration took place in the longitudinal sleepers, than to diminish their width, in proportion to the lesser breadth of the rail now used. At the same time the length of the rail was increased to 20 feet, and the longitudinals to 10 feet; an advantageous length for breaking the joints of the metal and of the timber, and also for effecting considerable economy in the latter item, as the shortness of the length allowed the use of pieces of moderate size.

The price of these sleepers per cubic foot amounted to about the same, as that of cross sleepers; but the large number of joints is a cause of instability, unless the cross ties be also increased in number, thus adding to the expense. This however really caused no increase of expenditure on the Baden line; because they had already used, with much longer longitudinal sleepers, cross ties at unusually small distances apart, but probably not more so, than was necessary.

When at length it was decided to repair a blunder, for adhering to which they had paid dearly, by altering the line to the ordinary gauge of $4'.8\frac{1}{2}''$, the longitudinal system itself was called in question. Attention once drawn to the subject, there could be no doubt in the matter; the system was condemned without hesitation, and probably irrevocably. Thus did the inverted ⊤ rail on cross sleepers eventually prevail in the Duchy of Baden, as well as throughout nearly all Germany.

It is difficult to conceive experience more complete, or more conclusive. Instability, the radical defect of longitudinal sleepers, would clearly have greater weight in France, than in Germany; where the traffic is not so great, the

rate of travelling less, and the maintenance staff generally more numerous, than in the former country.

117. The experiment has however been tried twice a few years ago in France. The bridge-rail, with two exceptions, was the one used, less fault being found with the sleepers, than with the chair-rail; and the longitudinal system was accepted, perhaps we may say, submitted to, in consideration of the particular advantages, attributed to the bridge-rail, on the strength of Mr Brunel's recommendation,

What are these advantages? One, an undoubted one, has already been mentioned; viz., that it does away with the non-supported sides of the head; to this advantage may be added another, that of the more thorough compression of the rolling surface; as it presents a flat surface to the action of the finishing rolls. These two are however the only advantages, and they are obtained at a considerable inconvenience; without taking into consideration the innate defect of this rail, that it is only applicable to longitudinal sleepers.

At the period, when the celebrated engineer of the Great Western, adopted this form, he endeavoured chiefly to counteract the tendency of the rail to overturn. The bridge-rail, combined considerable vertical rigidity with a reduced height, and a broad base, all of which were most advantageous for the stability proper of the rail; it was however only an imaginary danger, that he was fighting against. It is true the chair was at the same time done away with, in itself a real gain; but one possessed equally by the Vignoles rail, and which still leaves full liberty of choice of system for the sleepers.

The small height of the bridge-rail, is, truly speaking, less an advantage special to it, than a veritable source of inferiority; for, while widening its base, its height must be reduced, unless we determine to increase greatly the thickness of the sides; which, with a height equal to that of an inverted T rail, and having a thickness altogether only the same as its web, could not fail to be crushed in. This latter affords at equal weights much greater transverse resistance; not only because it is formed of parts, well connected together, but also because the proportions are better, which is an advantage not compensated for by continuity of support.

118. Mr Hemann, engineer of the South Eastern of Switzerland Railway, has had under consideration, for a portion of this line, a bridge-rail, in which the metal was distributed as follows:

		BRIDGE-RAIL of South Eastern line on longitudinals. Square inches.	VIGNOLES RAIL of North Eastern line on transverse sleepers. Square inches.
Area of. . .	Head..	2·27	2·45
	Body.	2·30	2·00
	Foot.	1·82	2·40
	Total area.	6·40	6·85

This rail, shown in Pl. IV, fig. 34, 35, and the inverted ⊤ one in fig. 31 and 32, were considered as equivalent, and fit for the same kind of work. The preceding comparison, however, shows one of the defects of the bridge-rail. The sides constitute as much as 36·12 per cent of the section, while in the Vignoles rail the web is only 29·34 per cent, although its height is greater; in the latter for both these reasons the distribution of the metal is much more favourable to transverse resistance : this argument can no longer therefore be advanced in favour of the bridge-rail, on the ground that it is supported throughout. Besides, this form does not permit of the foot being any further weakened to benefit the head; which in fact amounts, to the rail as a whole, being considered, as the compressed portion of a compound solid, the parts of which deflect all together. The above example affords an idea how far we may go in this direction; since the slight reduction of 6·7 per cent, is all, that continuity in the supports will allow of in the weight of the rail.

The present articles of concession granted to the French Railways, as did the old ones, allow of a greater difference, viz. 14 per cent; 70lbs per yard being the minimum weight for rails on transverse sleepers, and 60lbs for rails on longitudinal ones; here the question was simply one of safety for the line, and not of economy; a difference of 14 per cent may therefore be admissible under the former consideration.

The only real advantage therefore which remains to the bridge-rail is, that the sides of the head are not left unsupported.

Several solitary facts might tend, it is true, to prove, that in this alone it is, in itself, superior to the Vignoles rail: thus, in 1855, at the time of the alteration of the Baden Railways, it was found, that the bridge-rails were in a much better condition, than the others on the " Mein-Neckar " line (Grand Duchy of Hesse); both rails were laid down at the same time, had undergone precisely the same use, the same rolling-stock, and traffic; in fact everything was identical except the form and weight of the rail; the inverted ⊤ rail being considerably the heavier, and placed on transverse sleepers only 2′·11″ apart.

If, notwithstanding these results, the Baden engineers determined to reject the bridge-rail, it must have been on account of this superiority, appearing to them

to be due, rather to the quality of the rail, than to its form; and besides, that the fact even of its greater durability would scarcely be a sufficient compensation for the disadvantages inseparable from longitudinal sleepers, and chiefly from the radical defect of the joints. Although at this period, opinions were divided upon the merits of fish-plates, the Baden engineers perceived the no slight advantage of a rail, which, having the sides of its head projecting, was well suited for the application of this most natural method of strengthening the joint.

119. Attempts have been made on several German lines, laid with cross sleepers, to introduce longitudinal ones at the end span of the rails, as an aid in establishing continuity; which in fact amounted simply to replacing the joint-sleepers by two balks placed longitudinally in each line of rails : but this attempt, which had already been unsuccessful on the line from Leipsic to Dresden, and on that from Berlin to Breslau, between that city and Buntzlau, completely failed ; it has been repeated in France, with no better success, on the Northern line, as no good reason could be adduced, subsequent to the introduction of the fish-plates, for an arrangement of this kind.

120. It is so easy to accept as correct any decision, which has already been made, that there is no little merit sometimes in repeating an experiment, which has previously been tried, although it has on the former occasion given unsatisfactory results; the first trial should however have been, either insufficient on some account or other, or else the new conditions must be somewhat more favourable : it may therefore be supposed, that the line from Bordeaux to Bayonne, which crosses, or skirts pine forests producing an abundance of very regular timber, may have appeared more fitted, than most others, for the application of the bridge-rail on longitudinal sleepers.

This in itself should not, however, have been sufficient to determine in favour of renewing the experiment; to render success probable, they ought to have been in a position to remedy some of the serious defects, which past experience had pointed out in this system. Such however was not the case; the former blunders were repeated, and reproduced, under circumstances, as unfavourable as before ; and which of course could but lead to a similar result.

The trial referred to was devoid of every trace of real improvement, it only confirmed the facts already observed; however it decided the question in France, and will doubtless prevent engineers in future from embarking in such profitless experiments : considered thus negatively, it may be useful, and on this score only, can there be an interest in at present describing it.

121. On the Bayonne line (Pl. V, fig. 26) the rail weighed 60lbs per yard, in 19'·8" lengths; the longitudinal sleepers were from 13'·0" to 19'·8" long; the joints of both lines of longitudinals rested on the same cross tie; at first it was only when the balks exceeded 13'·0" long, that an intermediate cross tie was used; they were, as on the Baden line, placed underneath the longitudinals instead of on a level with their underside, as on the Great Western; they were fastened to them by long bolts, placed on each side of the rail, with the head uppermost, and a nut with claws to it. The rails were fastened to the longitudinals by bolts with the nut below, passing through the foot, and placed 3'·3" apart, the inclination being given by the slope of the upper face of the longitudinal; on account of the difference of length in these last, the only rule observed in the distribution of the joints of the rails, relatively to those of the supports, was not to allow them both to occur at the same point.

On the delicate subject of the joint of the rails, the method adopted was anything but novel; it was indeed one, that was at first sight naturally suggested by the form of the rail, and by the strains to which it was subjected; it was in fact a cover-joint on the underside, formed of a plate of iron, slightly raised in the middle, and sunk in a notch in the longitudinal, so as to be flush with its upper surface. On each side of the joint it had four holes; two and sometimes three being filled by rivets, and the rest by bolts, which connected it with the sleeper.

As before observed (67), the bottom plate with bolts had been already tried in Prussia; but its advantages as a cover-joint were counteracted by the play, necessarily allowed for expansion (122).

When the rivets were, as is usually the case, put in hot, no amount of play could be counted upon; even if they, by being hammered, had not filled up the holes (80). The friction developed by the tendency of the rivets to contract is so great, that it is the only strain, which takes place in boilers, in wrought iron girders, etc.; and so great also, that rivets are never subjected to shearing strains, even under the greatest pressure to which they are in practice submitted (*). Under these conditions the rail ceases to be free, notwithstanding the play, and the oval form of the bolt-holes; for this freedom to exist, the rivets must be cold, when put in, and of a metal sufficiently malleable to take readily the shape of the head.

On the Bayonne line, the riveting was done, while hot, and no play allowed; the resistance of the rivets was thus calculated on to destroy the tendency of

(*) See the report addressed to the French Minister of public works "On the application of wrought steel plates to steam-boilers" by Messrs Combes, Lorieux and Couche. Page 5, etc. Paris, Dunod, 1861.

the rails to contract, and the connection with the longitudinals to counteract the expansion, which takes place between fixed points, under the influence of a high temperature. An attempt of this kind, in a climate so warm, as the South of France, was certainly a bold one; it was not however successful.

The inconveniences, observed on the Bayonne line, were not all of equal importance; some were accidental, and not belonging to the system; others were a consequence, if not of the principle itself, at least of its method of application.

From the very commencement the following defects were perceived in this arrangement.

1st In certain details in the form, and in the quality of the rails.

2nd In the method of joining them.

3rd In the arrangement of the cross ties, between the longitudinal sleepers.

4th In the nature of the ballast.

1st *Rails.* — Their convexity was too great; a defect which was aggravated by the excessive weight of the entire rolling stock, and especially of certain engines, since altered, owing to the bad distribution of the load per axle; in fact every thing combined to exaggerate the pressure of the contact due to the wheels.

This is not, however, sufficient to explain the rapid destruction of the rails, when the line was first open to traffic; it was augmented by their inferior quality of metal, as is sufficiently proved by the nature of the damage, which they show; the rails were not crushed, they were split longitudinally, along the line of motion. So great, on the other hand, was the brittleness of the metal in the foot, that simply boring the rivet-holes produced fractures : these serious imperfections acted differently upon rails from different foundries.

Too much had, no doubt, been expected from the influence of continuity in the supports; besides the rail, independently of its shape, was too light.

nd *Joints of the rails.* — The complete absence of play at the joints was all the more injurious in its effects, in proportion as iron is naturally little suited to diminish the mischief which might occur. A considerable number of joint plates were broken by frost; while during the heat of summer the rails presented a series of horizontal, and vertical undulations, most injurious to the sleepers, and to their fastenings.

Making the bolt-holes oval, and introducing a perceptible amount of play at the ends of the rails, when at a low temperature, would entirely change the conditions of resistance in the joint; without taking into consideration the fact, that the holes from their position are very liable to become stopped up, which

is not the case with the holes of the fish-plate bolts; so that in reality the force of one of the principal objections against the bridge-rail depends on the amount of actual play allowed at the joints.

122. ***Observations on the amount of play to be allowed for expansion.*** — In a discussion on this subject, at the Institution of Civil Engineers in London, Mr Brunel was strongly convinced of the inutility of allowing any play; this conviction was founded, he said, on most conclusive observations; it was perfectly clear to him, that no undulations of the rails, either vertically or laterally, nor breakage of the joints, nor straining of the metal need be feared, when the rails were well fixed to the longitudinal sleepers. But we must remember Mr Brunel was only referring to railways in England; and, that he reserved his opinion on this subject, with regard to lines in warmer climates, where the variations of temperature are greater.

In Bavaria, the commission on railways, in examining the question anew, arrived at the conclusion, that play is not only absolutely necessary, but that it would be an advantage to increase it.

In fact, excepting certain cases which only apply to English railways, and also the Barlow system of permanent way, to be referred to further on, the necessity for a certain amount of play is perfectly proved. Every system which does not unite this condition, with a complete connection of the joints, is defective in this respect, at least; as this is the case with the bridge-rail, it ought to be rejected, and this should be done even if it possessed no other defect, than that of being inseparable from longitudinal sleepers.

On the French lines it is admitted, that the temperature of the rails may vary between 14° and 86°; which, on a bar of metal twenty feet long, will produce a variation in length of $\frac{1}{8}$ of an inch. The amount of play is often somewhat exaggerated, to allow for the deformation of the ends, which then have a tendency to fill up a part of the vacant space with the metal, which is pushed out of place.

No especial care is taken to allow exactly the amount of play, due to the actual temperature at the time of laying the rails: on the Western of France for example the variation is $\frac{1}{8}''$ up to 41°, $\frac{1}{16}''$ between this and 68°, and $\frac{1}{12}''$ above that point: on the Northern it is $\frac{1}{8}''$, when the temperature is below 50°, and $\frac{1}{16}''$ above it. The plate layers are provided with small wrought iron gauges of exactly this thickness, and with a thermometer, to be placed in the shade.

In laying a rail, it is to be applied exactly against the gauge: to avoid pressing together the other joints it is better to leave two, or three plates in their places.

On some lines open to traffic, several adjoining rails are often found in contact, even at a moderate temperature; the harm is trifling, so long as the resistance, distributed throughout the length of rail now rendered continuous, is not sufficient to prevent them from expanding with an increased temperature, by overcoming the resistance, to which they are subjected, and taking advantage of the spaces existing at either extremity. But if contact exists between too many consecutive rails, the middle rail especially is in such a state of compression, as is likely to cause splits near the surface at the ends.

The edge of the rail-head is sometimes chamfered off to prevent this effect; but it is better to remove the cause itself, by seeing that the spaces are regularly left.

The result of absence of longitudinal play in the rail might have been more serious still, when the rails acted independently of each other; the application of fish-plates however has effectually prevented this, which is therefore another advantage arising from them.

123. 3[rd] *Arrangement of the Cross Ties.* — As the object of these ties is to counteract any tendency on the part of the longitudinal sleeper, to slip, to overturn, or to deflect horizontally, they must fulfil this threefold purpose by the best arrangement, as to number, position, and method of fastening.

They may be placed under the longitudinals, as on the Bayonne line (Pl. VI, fig. 40), and on the Duchy of Baden line (Pl. IV, fig. 28); or between them, on a level with their lower face, as on the Great Western.

The connection is effected in the first case by means of vertical bolts; in the second by horizontal screws, passing through the longitudinal in the middle, and terminating in flat plates bolted to one of the sides of the cross ties, which is morticed slightly into the longitudinal.

Let T and T′ represent, respectively the tensions of the vertical bolts, and of the screws, necessary to prevent the rotation of the longitudinal sleeper, under the action of a horizontal thrust Q, due to the flanges of the wheels; then, neglecting the vertical reaction of the wheels upon the rail, and also the horizontal reaction of the ballast upon the longitudinal, and representing by e, and l, its thickness and its width, and by r the elevation of the rail, we have

$$T = \frac{Q(r+e)}{l}, \qquad T' = \frac{2Q}{e}(r+e), \text{ whence } T : T' :: e : 2l.$$

$$\text{Generally } e = \frac{l}{2} \text{ nearly.}$$

Consequently, as far as motion is concerned, the first arrangement is much the best, which is an important consideration; for, if there is but little fear of the rail itself turning over, it is not so with regard to the rail and sleeper combined, which are more easily acted upon, owing to their greater height. But the second arrangement is much more efficacious in preventing slipping, which is counteracted by the resistance of the screws to extension. There is no possible comparison between the vertical bolts in the first case referred to, and the pegs, spikes or screws, which fasten the rails, or the chairs, to their supports. In the latter, the projecting portion is very short, and as generally the length of the fixed part exceeds but slightly its breadth, it has no tendency to deflect, and its transverse resistance only, or nearly so, is called into play.

The bolts of the cross ties are far differently acted on; the great distance between these ties causes a very considerable pressure to be concentrated upon them; but chiefly are they exposed to the reaction of the longitudinal over a considerable length, equal to its entire depth; they have also a tendency to bend, or at least to increase the size of their hole, which weakens the timber a great deal. Besides it is evident, that the friction developed by the tension of the bolts, which is necessarily limited, and moreover influenced by the state of humidity of the wood, is but slight. To embed the longitudinal partially in the cross tie does not appear to be capable of being so accurately done, as to ensure a uniform breadth of gauge, especially when soft woods are used.

Placing the ties inside has the additional advantage of requiring less wood.

The position of the ties under the longitudinal is, moreover, opposed to the principle of continuity in the supports; or, in other terms, to the complete identity of all parts of the rail throughout its whole length, with reference to the vertical reactions, acting from below. Its deflection depends on the compressibility, and consequently on the thickness, of the ballast; and, as this is always less at those points where the ties occur, the same is necessarily the case with its consequent.

It therefore appears, that Mr Brunel's arrangement is much the best; the other seems to have originated, with the idea of a mixed rail, being assimilated to a permanent way on transverse sleepers; in this attempt however no account is taken, either of the very great difference in the distance between the cross sleepers, or of the increased height from the top of the rail to the sleeper.

With the cross sleeper system, there never can be more, than one wheel at the same time on a span; so that the rail, besides being much lower than the

mixed rail, can neither be put out of shape laterally, nor be overturned : with longitudinal sleepers, the cross ties, from their greater distance apart, cannot exercise the same functions. The mixed rail, if it is too weak, and is embedded in a ballast, which, owing to its small amount of consistency, offers no lateral support to it, gets out of line between the points where the ties occur, and their fastenings become loose, if they are not arranged so as to resist the lateral thrust exercised by the two wheels of the engine at the same time.

This is what happened at the outset on the Bayonne line; the longitudinals acted precisely, as a too slender rail would have done, if supported by sleepers much too far apart, and united by insufficient fastenings : the bolts bent, the longitudinals slipped on the cross ties, causing the gauge to widen out, and the trains to run off inside: while at the same time the sleepers frequently split under the enormous pressure of the bolts, necessarily very close, not only to the edge, but also to the end of the longitudinal, in consequence of the narrow width of the cross ties.

A certain degree of haste, necessitated by particular circumstances, and the blunders engendered by it, especially when the system is novel to those entrusted with its execution, at first greatly increased these drawbacks, which were not all inherent to the system; they were diminished, but not entirely overcome, by adding an intermediate tie to all the sleepers the length of which exceeded 13 feet; while by still further increasing the number in curves, as well as by adding iron plates having a hook at each end to catch the foot of the rail, and at the same time augmenting the thickness of the ties from 4" to 5", sinking the longitudinals 1 $\frac{1}{4}$" into them; and by using bolts $\frac{3}{4}$" in diameter, instead of $\frac{9}{16}$", they were again reduced.

4th *Ballast.* — It is certain also, that the fineness and looseness of the ballast, at first the sand of the Landes was used, since replaced at great expense by gravel, was to a great extent the cause of the instability of the Bayonne line, and of the want of connection in its various parts.

No permanent way, no matter of what system, can be effective without good ballast (174); this condition is still more necessary for lines with continuous supports than for others, as they especially require to be well packed up; with a fine dry sand longitudinal sleepers soon get loose. The change of ballast was also necessary in order to get rid of the constant cloud of dust which accompanied the trains, and which was as injurious to the engines, as annoying to the passengers. The alteration, which cost nearly £ 400 per mile, certainly improved the line, but its inherent defects remained, especially the irremediable one of the joints; so much so, that eventually the company was compelled to adopt the chair-rail, on cross sleepers.

124. *Permanent way of the Auteuil line.* — This line is remarkably similar to the preceding, having the same essential characteristics; namely, ties underneath, bolted through; and connecting pieces riveted at the joints.

But in the details there were some important differences; the longitudinals and the cross ties had the same dimensions 12″ × 6″; the ties, on an average 8 feet apart, were fixed, at the joints by four bolts, in other places by three only. The length of the longitudinals, of fir, was between 13 and 14 yards, which introduced a certain irregularity, though of no great consequence, in the arrangement of the ties; here also, as in the Bayonne line, they did not confine themselves to 20′.0″ rails only, which further diminished the chances of the joint of both rail and sleeper coming together.

The joint plate was very large, 16″ × 6″; and, when the line was laid at a moderate temperature of about 50°, a space of from $\frac{1}{8}$″ to $\frac{3}{16}$″ was left between the ends of the rails, which required the four holes on one side of the joint to be of an oval form : if however this arrangement prevented rebound between the rails, it lost much of its value on the score of continuity of resistance.

The inclination was effected by the slope given to the longitudinal; that is to say, by its bearing upon the cross ties not being level.

The rail was 6″ broad, and rested on sleepers 12″ wide; this great excess of width, favourable in other respects to stability, was in this case necessitated by the particular arrangement of the fastenings : the wood screws, instead of being on a level with the upper edge of the foot of the rail, and fitting on it with their flattened heads, pressed on small cast iron blocks, which bent back over the rail : these fastenings, about 20 inches apart, alternated on either side, except at the joints where they were opposite to each other.

The utility of these intermediate pieces is far from clear; the stability of rotation of the rail was already assured; there would of course have been no inconvenience in reducing it had there been anything to compensate for it, but useless, if there be nothing to do so : as, allowing that the rail has a tendency to revolve upon the outer edge of its base, the tension existing in the inner screw, which counteracts this tendency, would be almost doubled by being placed directly in the middle of the block. But the proportions of the bridge-rail, exclude all fear on this head, which is an impossibility even with rails of much greater height. To justify this arrangement however, it is not only sufficient to show it does no harm, but also that it is of some use.

The Auteuil line, worked by engines with the hinder wheels coupled, and consequently not allowing any play in the axle guards, has very sharp curves of 15, and even of 12 chains radius; in order to preserve the gauge in these curves flat iron tie bars were placed, as was afterwards done on the Bayonne

line, which doubled over the edge of the rail, and were bolted to the sleeper.

The following is the cube of timber used :

	Cube feet per mile of single way.
Longitudinal sleepers (10,874' × 12" × 6")	5,437
Cross ties 10'·0" apart (7'·0" × 12" × 6")	1,848
	7,285 c. f.

The rails were prepared beforehand with the joint plate riveted to one of the ends, the rail was laid on the sleeper, and the notch for the plate marked and cut out, the riveting at the other end was performed with a portable forge; the small blocks and screws were used, as on the Bayonne line. This arrangement ended, as the previous one, in discarding the bridge-rail, and the longitudinal sleeper.

125. *Original permanent way on the line from Dôle to Salins.* — The directors of this short line adopted the bridge-rail with longitudinal supports, which were not however continuous. The sleepers 8 to 9 feet in length were separated by intervals intended to facilitate the drainage of the line; the rails 20 feet long were fastened by spikes, formed of compressed wood, at the joint a wooden plug was inserted in the hollow of the two consecutive rails. The connection between them was effected by means of cross ties underneath, at the junction of two consecutive longitudinals; and to which they were fixed by wooden pegs, penetrating only about an inch or two into the tie; they were however soon replaced by iron ones.

Economy was here the object in view; it was admitted, that a 60 lbs. rail, under the above conditions, was equivalent to a 70 lbs. one, on cross sleepers.

The application of this singular system, commencing at Dôle, on a length of about nine miles, was suspended in consequence of the purchase of the line by the Lyons Company, which soon altered this arrangement. It would indeed have been difficult to have grouped together more elements of instability, than existed in this case; it was in fact no longer the sleepers, that supported the rails, but the rails that kept the sleepers apart; as these oscillated up and down upon the intermediate cross tie, like the beam of a balance, and, when they were removed, the pegs were found to have no hold, so that the ties remained in the ballast.

126. The original Company of the line from Blesme to Saint-Dizier left to the Eastern Company a permanent way laid on the same system; the materials thereof were removed, as soon as possible, to station sidings, where the rails are generally laid on cross sleepers, which have been removed from the main

line, but which are still useful: with the bridge-rail these sleepers were only placed 2 feet apart.

In fact, the bridge-rail at the present time has but a very limited application; only on certain iron bridges. The section is not always symmetrical; the head of the rail being inclined to 1 in 20, while the foot is horizontal (Pl. III, fig. 16 and 17).

127. *Line from Saint-Rambert to Grenoble* (Pl. V, fig. 5; Pl. VI, fig. 39). — If the use of longitudinal sleepers is far from being justified by the advantages, belonging to the bridge-rail, we can well conceive, that they cannot be advantageously employed with those forms of rail, which can quite dispense with them. The short line from Bourg-la-Reine to Orsay, and since then that from Saint-Rambert to Grenoble, have however adopted this course.

The longitudinal sleepers, $11'' \times 5\frac{1}{2}''$, were placed on cross ties $8'{\cdot}2''$ long, $6'{\cdot}6''$ apart; and fixed to them by long bolts. The joint of the longitudinals did not correspond with the middle of the ties; so that only one longitudinal could be bolted at each joint. The only object of this arrangement, which was equivalent to considering the two longitudinal sleepers, as constituting, by means of the rails, a system sufficiently connected to render a single fastening to each tie all that was necessary, must have been not to weaken the tie, by only inserting a single bolt; and that one nearly through its axis. This however was not strictly adhered to in practice, for in some cases there was often between the ends of the longitudinals a space of more than two inches; so that, the one, which received the bolt, had no greater length of bearing, than the other.

The large bolts, *b* (Pl. VI, fig. 39), placed on the outside, have no tendency, as in the opposite position, to split the sleepers under the action of the horizontal pressure of the wheels; at the same time however they fail to fulfil one of their essential duties, viz., to prevent its turning over. The consequences of this faulty arrangement were soon apparent on the Saint-Rambert line; the longitudinal sleeper separated slightly from the tie; the gravel got between the two, and the aperture grew gradually larger.

The spikes, which fixed the rail to the sleeper, did not alternate on either side; they were $3'{\cdot}10''$ apart, which seems excessive: on ordinary lines the distance, which is always less, is limited at least by that of the cross sleepers. With longitudinals, however, instead of augmenting the distance apart, it is only natural, to profit by the facilities they offer, to reduce it; as the connection would thereby be more perfect, and the pressure, being more divided, would strain the longitudinal less.

The small breadth of the rail used, compared with the bridge-rail, was a real advantage, when laid with horizontal sleepers; it allowed of a sufficient distance, 3″, being left between the spikes and the edges of the sleeper; whilst at the same time the breadth of the timber was reduced to 11″.

It was considered necessary to apply at the joints every combination, that was known: 1st Fish-plates with four bolts; 2nd A joint plate, *m*, with raised edges; 3rd Cover-plates *r*, *r*, fastened on the edges of the foot by two strong bolts, with nuts on top, passing through the sleeper; 4th A bottom plate, *i*, to aid in screwing up.

This is evidently more than necessary; for with fish-plates, all the rest was useless.

The rail was left free to expand; as the holes in its foot for the bolts of the joint plate were oval in form.

The following was the cube of timber per mile of single way:

		Cube feet per mile of single way.
Longitudinal sleepers	(10,560′ × 11″ × 5½″)	4,469
Cross ties. (With each 20′ rail	1 joint 8′·2″ × 11″ × 5½″; 2 intermediates 8′·2″ × 6″ × 6″)	1,991
		6,460 c. f.

It would have been difficult to discover in this attempt any chance of that success, which had been wanting in all others of the same kind. Either in this trial it was very small; or an error had been committed on the Baden railway at the time of relaying the line, in abandoning an arrangement of a similar character, and which besides was better understood in its details. But we are hardly able to judge of the motives, which led to these two contrary determinations, especially when we see, that one of the considerations urged for the Saint-Rambert line was the simplicity, and economy of the maintenance of the line on longitudinal sleepers; the true worth of which assertion was shortly made manifest by experience.

It was proposed to lay the line in a very solid manner, chiefly because the engines in use on this line (Engerth's system with 4 wheels coupled), had nearly 13 tons of statical load on the axle of the driving wheels, and nearly as much on the axle of the front ones. If there is any effectual plan to counteract an exaggerated load upon the rails, it is surely not to be found in the substitution of longitudinal for cross sleepers; an increase in the weight of the engines is far from constituting a new argument in favour of the continuity in the supports.

The original company of the Dauphiny line, later on, showed much wisdom

in abandoning this unfortunate combination, of the Vignoles rail with longitudinal sleepers, and reverted to transverse ones.

128. The Metropolitan offers the most recent, and what will probably prove the last example, of the Vignoles rail laid on longitudinal sleepers.

This rail is unusually broad in the foot; which is the more apparent, as, even with an equal breadth, it would have had a much more extensive bearing surface on longitudinal, than on cross sleepers; but this extent of surface is not, in reality, so excessive as it appears. When it was adopted, there existed the example of the bridge-rail, which, notwithstanding its broad base, penetrated into the wood; this is however a necessary consequence of the imperfection of the joints, of the general loosening of the fastenings, and of the tendency of the wood to open : with the inverted T rail, laid on longitudinal sleepers, the first cause of the destruction of the timber disappears; the others, however, remain. Having then once adopted the system, it became a matter of prudence to neutralize the action of these causes, by distributing the load over a broader base; but supposing this sufficed, there still remains a fresh disadvantage attached to longitudinal sleepers, that of requiring for the inverted T rail proportions, which are defective in themselves.

On this line, the rail is fastened by means of wood screws, passing through the foot; an arrangement seemingly necessitated, as in the bridge-rail, by the great breadth of the foot : for the fastenings, if placed on the outside of the rails, would have been too close to the edges of the sleepers. The holes, pierced in the foot of the rail, leave it very little longitudinal play; this however seems of but little moment for a line, which is underground throughout its length, and consequently exposed only to slight changes of temperature.

129. On several sections of the Great Western, the longitudinal sleepers are protected by wooden packing pieces, joined together under the rail, and with their fibres running crossways : by this means the destruction of the sleeper, partly due to the sinking in of the fibres underneath the rail, which receive but little support from the outside ones, is delayed; the packing piece distributes the pressure, it receives all the jolts from the up and down movement, inseparable from the bridge-rail, and in addition is easily replaced. But a system, which requires such an aid is already condemned; yet this is only a minor defect.

Even in England the bridge-rail will hardly have survived Mr Brunel himself:

it has been abandoned over the whole length of the Great Western; and, no doubt, the longitudinal sleeper will shortly follow it.

130. It will only however have been abandoned, after having been thoroughly investigated, and after having been tried in every shape. Thus, in 1856 it was tried on the London and North Western, and on the South Western; Mr Seaton's saddle-rail may still be found on the line between London and Bristol placed on triangular longitudinal sleepers *t*, *t* (Pl. VI, fig. 43 and 44), to which it is fixed by screws *v*, *v*; there is at the joint a plate, *p*, bent over into an angle iron; which, whatever may be said to the contrary, acts simply as a joint-plate protecting the wood against the vibrations of the rail, and in no respect strengthening the connexion. The cross ties T, also triangular, are placed underneath the longitudinal; to this there is no objection, as far as overturning is concerned; for the total height is reduced by the top of the sleeper being inserted in the hollow of the rail.

No matter however in what way the details be modified, the loosening of the fastenings, and imperfection of the joints, the radical defects of the system, will always exist.

Admitting even, that the picked timber, required for longitudinal sleepers, could be obtained at the same price, as that for cross sleepers; in order to make the former appear the more economical in first cost, it must be shown, that all other matters being equal, the weight of the rail may be considerably reduced, which is by no means the case : on the score of maintenance, the longitudinal system is undoubtedly the more costly.

There is one advantage attributed to longitudinal sleepers, and generally admitted without question; the true worth of which ought however to be made known; viz., the small amount of injury, arising from trains partially running off a line on the longitudinal system. It is true, that, if the wheels continue on the longitudinals, the accident is less serious, than if it occurred on cross sleepers, from the jolting of the carriages being less violent; but as this may be of longer duration, the damage may be eventually as great, if not greater. Thus on the Bayonne line, waggons, after leaving the rails, went several miles, without either driver, or guard perceiving the accident; the permanent way nevertheless was greatly damaged throughout the whole distance, the longitudinals being broken and split, and the bolts bent; in a word, the injury was greater, than on a line laid on cross sleepers.

The only advantage possessed by lines on longitudinal sleepers is, that the fracture of a rail is harmless; it is not even necessary to replace it, for it is sufficient to treat the fracture as a joint, as was often done on the Bayonne line; a

saddle was fixed to it by means of rivets, or by temporary bolts, which were replaced by rivets when the number of fractures was sufficient to require the use of the moveable forge; but it is impossible seriously to attempt to counterbalance with an advantage of this kind defects, which add so greatly to the cost of maintenance, already so large on lines with a more perfect system.

Though experience had condemned the form under which continuity in the sleepers has been applied, the principle itself has not been definitively decided against; perhaps with a permanent way entirely metallic it may recover, from the more or less serious, but incontestable check, which it has experienced with timber longitudinals.

131. Excepting on works of art without ballast, where longitudinal sleepers are often applied, either with the inverted T, or with the bridge-rail (126), as a guard against the consequences of fracture in the rails, their employment is of little utility upon a main line, unless as an expedient in certain particular cases; for example, to re-establish quickly the traffic when a partial slip in an embankment has taken place. Also they may generally be of use where there is any doubt, as to the ground being solid; thus, some slips occurred at several points upon the line from Paris to Strasburg, in the department of the Meurthe, especially in the cutting called "du Pendu" : some borings, down under the line, and reaching to a bed of clay very full of water, proved the existence of a slight subterranean current, about parallel to the adjoining river, the Sarre, but below its level; it was the gradual washing away of this clay which caused the slips. Apart from the cost, it would have been out of the question to drain at a depth of 23′ below the surface of the ground, as well as beneath the bed of the river; happily no recurrence of these slips has taken place for some years. The solution of this somewhat difficult problem, and which was adopted in principle, would no doubt be, to place the cross sleepers upon longitudinal balks fixed on piles, driven down into the solid ground below the clay.

CHAPTER V.

CROSS SLEEPERS.

§ I. — Their form and dimensions.

132. The necessity of embedding in the permanent way, enormous masses of wood, over 200 cubic yards per mile of single way, constitutes, for the establishment and maintenance of railroads, a very heavy charge, and the heavier as the traffic is less. The sleepers are not, in fact, like the rails, which in this matter are placed under conditions, as favourable, as they are unexpected; viz., working instruments the wear of which only depends upon the amount of use which they undergo; if the action of the trains forms a considerable part in the destruction of the sleepers, the influence of the exterior elements, combined with the reaction of the inherent qualities of the different kinds of wood, contribute to it more actively still. Railway Companies have long sought to lighten this heavy burden, either by prolonging the duration of the wood, or by substituting more durable materials. The first object has been attained to a certain extent, but not sufficiently so however, to allow of our ceasing to prosecute the second; where the advances made up to the present have not been so decided. Nevertheless, the abatement in the price of iron has given to these researches a fresh impulse; and, as we shall shortly see, recent attempts seem to have effected some real progress.

That wood will soon cease to be the essential basis of railroads is a statement, which many engineers refuse to believe. The more the proper requirements of the public, and those of traffic itself, conduce to the augmentation of speed, the more, say they, does the use of wood seem indispensable: for it alone, according to them, naturally fulfils, so to speak, the necessary conditions of flexibility, of bulk, and of quantity, which a high speed of travelling imperatively demands. Not only does it guarantee security, but it also preserves the rolling stock, and the rails from the rapid destruction, which is observed upon certain lines with an entirely metallic permanent way. Nowhere has this fact been more clearly proved, than upon the Indian lines; which have most of them resumed

the use of wood, notwithstanding the destructive influence of the climate upon it, after having made use of both wrought, and cast iron; but perhaps the failure of the metal should be imputed, rather to the defective form of the supports, than to the material of which they were made.

133. Sleepers may differ : 1st in form; 2ndly in size; 3rdly in kind.

1st *Their form.* — Their section may be rectangular, semicircular, or both forms combined (Pl. VII, fig. 24). The triangular form, having been tried on several occasions, has been entirely abandoned : for this triangular prism, carrying the rails upon a horizontal surface, had a tendency to penetrate like a wedge into the ballast, and also to turn over on its lower edge : their instability, giving to them the name of dancing sleepers, has caused them to be universally abandoned.

The rectangular section is the one most widely used; the exact form, depends upon the nature of the wood and upon the method of using it, whether in its natural state, or prepared; and also upon the mode of preparation itself. Thus oak, employed in its natural state, is always square, the portion next the bark, which would not resist decomposition, being previously removed; when prepared, it may, and it ought even, in general to preserve this portion, which alone is completely penetrated by the preservating composition; in this case the half round form is preferred.

Soft woods, with rare exceptions, decay too quickly to allow of their being employed without preparation, while the heart, impenetrable to the greater number of the preserving fluids, forms but a very small proportion; of the whole; in form they may be, either square, or half-round. Thus, the "Boucherie" method, which is applicable only to timber with the bark on, produces half-round sleepers, which certainly may afterwards be rendered square; while by the "Breant," and those derived from it, as well as the "Bethell" process, sleepers of either form may be prepared.

Considered in themselves, these two forms are nearly equivalent; the half-round section requires a little more labour in shaping it, and moreover it needs to be a little larger, which is an advantage in certain respects. — It is however only a question of price, and of conditions of locality.

134. 2ndly *Their Cube.* — The sleeper ought to afford stability by its own size, and by the pressure of the ballast upon its sides. For the square form they usually cube about $3\frac{1}{4}$ c. f., and for the half-round about $4\frac{1}{2}$ c. f.

Each of the three dimensions, length, thickness, and breadth, has a special duty to perform, and cannot be reduced below a certain limit.

The length 8'·2", though it may appear excessive, is none too long for the ordinary gauge; experience proves that its reduction, even if compensated for by an increased breadth, is injurious in its results: as it also shows the necessity of a great excess of width of the general bearing surface upon the ballast.

Their thickness must not be too slight, as this would weaken them, and the spikes be wanting in holding power; besides the excessive difference between their girth, and the area of the section, in this case would be hardly favourable to their durability.

By their breadth, once their length is fixed, they should perform a very essential condition, that of distributing, over a surface of ballast sufficiently broad, the load applied upon the sleeper, a weight which is about equal to that of the most heavily loaded pair of wheels. A lesser breadth in the sleeper cannot therefore be compensated by their being placed nearer to each other; for the essential point is not the total amount of bearing surface for a certain length of line, as this may vary with the section of the rail, which admits of the sleepers being wider apart in proportion to its strength, but it is the bearing surface of each sleeper which is essential. No doubt they ought to be so close together, that the weight of the whole, or of any portion whatever of a train, may be spread over a total surface sufficiently large; but considering the nearness of the sleepers, which is indispensable for all rails, even the heaviest, it is not necessary to pay particular attention to this condition; which is amply fulfilled, if each individual sleeper has its proper proportion of bearing surface.

Upon the Eastern of France Railway the sleepers are of the following dimensions (Pl. VII, fig. 24):

Length.		8'·4" to 9'·0"	
		Square.	Half-round.
Thickness.		5" to 6½"	5½" to 7"
Breadth.	Intermediate.	8" to 10"	10" to 14"
	Joint.	10½" to 12"	

The bearing surface of the sleepers therefore varies from 6 to 10 s. f.; which gives, under the weight of a pair of wheels of 13 tons, a pressure of from 35 to 20 lbs. per square inch of ballast.

Upon the Paris and Mediterranean line, the minimum dimensions are:

1st For oak, and beech, both square:

	Intermediate.	Joint.
Length	9'.0"	9'.0"
Breadth	8"	12"
Thickness	6"	6"
Minimum cube	3'.0"	4'.6"

2ndly For beech, half-round:

	Intermediate.	Joint.
Length	9'.0"	9'.0"
Extreme breadth	8"	12"
Extreme thickness	6"	7"

Upon the Orleans Railway, the length varies, from 8'.2" to 9'.0"; with square oak sleepers, the breadth varies, for intermediates between 8" and 9", and for joint ones between 12" and 14"; the thickness between 6" and 8" for both descriptions: with square beech and pine, the breadth varies from 7" to 11" for intermediate, and from 11" to 14" for joints; the thickness common to both is between 4" and 6".

Upon most of the German lines, the joint sleepers are not only larger in size, but are also longer, which often renders them very expensive; and it is the doing away with these special sleepers which is, as we have already seen (74, 75) one of the causes of the preference, though somewhat unforeseen, of the unsupported joint with the inverted ⊤ rail. But these large dimensions of the joint sleeper are really superfluous; it is with these as with the joint plates, the use of fish-plates renders them no longer necessary. This does not imply that a lengthy and strong sleeper is not preferable to a short and slight one, but only that so great a disproportion between the joint and intermediate sleepers is no longer necessary; as this idea was formed, when each rail constituted a system without any real connection with its neighbours. The dimensions of sleepers are still, upon a great number of lines, the same that they were twenty years ago, notwithstanding the greatly altered conditions of speed and of the weight of the engines; the gradual increase however in their price would not allow of any augmentation in their size.

In England sleepers are usually $9'.0'' \times 10'' \times 5''$, and 3' apart from centre to centre, giving a bearing surface per sleeper, as well as per yard of line, of $7\frac{1}{2}$ f. s.; upon some railways with very great traffic, they are only 2'.6" apart, which adds one sixth to the bearing surface per lineal yard of single way; an addition no doubt of great utility as regards the wear and tear of the rails, but which, as far as the distribution of the pressure upon the ballast, and the sta-

bility of the supports is concerned, is less efficacious than an augmentation in the breadth of the sleepers would be.

English engineers however generally adhere to uniformity in the dimensions of the sleepers, and in the distance between them; except perhaps for the joint ones, which are placed as close as proper packing up will allow of.

Upon the Northern of Spain, with a gauge of 5′·6″, the sleepers are 9′·2″ in length, and contain 5 cubic feet.

In the United States, one of the numerous causes of the imperfection of the permanent way is the insufficiency and irregularity of the dimensions of the sleepers, which are only upon an average 8′·0″ long, and 7″ in breadth; they are looked upon merely as ties, designed to maintain the gauge, other conditions equally important being also overlooked; and thus, the sleepers are laid down irrespective of their length, or of their size.

Long and broad sleepers may afford a sufficient bearing surface, if they are closely packed only under the rails, while the portion in the centre of the line remains but slightly done. With the sleepers in use in America, this would be totally insufficient; though matters are but little better, even where the sleeper is packed throughout its whole length. For owing to its vibrations, first one end up and then the other, its effect is soon counteracted, especially towards the ends; if their number be augmented, their economy is at an end, and besides the evil is not remedied, as each sleeper has of itself to bear nearly the entire weight of each pair of wheels. When they are too near each other, packing up is rendered very difficult, they become also very unstable, springing up under the transit of the trains; nothing is more common in the United States, than to find a sleeper suspended from the rail, causing thereby an excessive deflection of the latter when under the load, as well as concussions which destroy the wood, and a reaction, whilst the rail recovers itself, which loosens its fastenings.

In fine, though an excessive pressure upon the ballast is in no way inherent to the principle itself of disconnected supports, as a matter of fact, and from imperative considerations of economy, this exaggeration often takes place; augmenting the current expenses of maintenance, as well as of depreciation in materials. As several engineers have remarked, among others Mr Holley (*), and Mr Hartwich, the learned and able engineer in chief of the Rhenish railways, continuous supports may have the advantage in this respect; not that it is easier by this system, far from it, to have a greater bearing surface per unit of length of line, but because it avoids the chief inconvenience attached

(*) Work quoted, page 61.

to transverse sleepers; that of having to support separately, and consequently upon a very limited space, the weight of each pair of wheels. Longitudinal supports, it can be easily understood, provided they be rendered rigid, and the joints be made good, may distribute over a greater surface of ballast the pressure applied at any one point of it: this advantage however, as is very evident from the discussion upon longitudinal system (110 etc.), besides being so far purely theoretical, is purchased at the cost of very great inconveniences. The first condition, in order to render these advantages really effective is to renounce the combination of an iron rail upon a wooden sleeper, which constitutes the mixed rail.

Mr Barlow, with this object in view, made a first attempt, unsuccessful it is true, but which was none the less one worthy of note, its principal, if not its only aim, was to do away with the use of wood; Mr Hartwich has since made a similar trial, but conceived also with a view to the distribution of the load upon a larger surface of ballast. This subject will be reverted to in treating of metallic permanent ways (193).

125. 3rdly *Kinds of Wood.* — Oak, beech, fir, pine, and in a lesser degree hornbeam, are nearly the only kinds of timber in use upon the European lines; we may add to these the larch, one of the best kinds, when grown at a sufficient elevation. In Bavaria where it is pretty common, it has been observed, that those trees which have grown upon the sides of low valleys are of indifferent quality; generally however this wood is either so rare, or so difficult of access in the mountains, that it can be but seldom used.

§ II. — Durability of non-prepared sleepers.

126. 1st Oak. — Among the woods usually employed, oak is nearly the only one, which can be used without preparation, and yet be in a condition to be cut square; if sound, compact, and has been grown slowly in a good soil, it may in a ballast sufficiently porous, and in a well drained line, last from twelve to fourteen years. The influence of the soil is such, that the products of certain forests with too light a one are excluded from the market.

According to Mr Buresch, in 1863, and perhaps even still, upon the line from Hanover to Brunswick there were sleepers perfectly sound, which had been there for twenty years; they were it is true of excellent oak heart, they had merely been gradually hollowed out directly under the rails, their thickness being reduced to one half, so that the spikes projected below the lower face; this could have taken place with perfectly sound oak, only by the contact

between the rai and the sleeper not having been sufficiently ensured by the heads of the spikes (39).

It has lately been ascertained in that country, that of non-prepared oak sleepers 43 $\frac{1}{2}$ per cent had not been taken up at the end of sixteen years.

In Wurtemberg also some oak sleepers have been in use for eighteen years. To have lasted twenty years is certainly a remarkable durability for timber in its natural state, despite the causes of decomposition which act upon it; but as far as concerns the mechanical actions which take place, so long as the wood is maintained sound, it is not a question of time, but of traffic; the number of trains, weight of locomotives etc. Now in this respect a sleeper has certainly less wear in twenty years upon the Hanoverian railways, than in ten years upon the main lines, in either France, or England.

In England oak, though scarce, wears well; on the Midland Railway some sleepers have lasted over sixteen years, some even, on the Great Eastern, near Ipswich, have been laid down twenty-four years; such durability can however only be explained by the exceptional nature of the wood, and of the ballast.

Upon the line from Erquelines to Charleroi, opened in 1852, only 15·33 per cent had been changed in 1865, a result all the more favourable as the traffic on this line is considerable, these examples however are happy exceptions; thus upon another Belgian railway, the Luxemburg line, the oak sleepers have only lasted from six to eight years, according to the nature of the ballast.

Various German railways afford the following results :

" Saarbrück " : maximum duration, 12 years; mean 8 years.

" " Saarbrück to Treves " and " Rhein Nähe " : longest 15 years; mean 11 years; soil is very porous, and consequently favourable; on the other hand curves of 18 chains radius accelerate the destruction of both spikes and sleepers by the excessive strains to which they expose them.

" Nassau, " 8 years; soil but little favourable.

" Frankfort to Hanau, " 9 to 11 years.

" Neisse to Brigg, " 11 $\frac{1}{2}$ years in a clayey ballast; better results are expected with a more porous one.

" Magdeburg to Wittenberg, " and Rhenish railway, 9 $\frac{1}{2}$ to 10 years.

137. 2$^{\text{ndly}}$ Fir. — The durability of fir is very variable, as is its nature, but it is nearly always very limited; generally it must be replaced at the end of three or four years.

Its mean duration has been :

" Lower Silesia "	4 to 6 years.
" Brunswick lines, and on the Carl Ludwig (Gallicia)	5 years.
" Berlin to Anhalt "	6 to 7 years.

"Oppeln to Tarnowitz."	7 years.
"Bavarian state railway, wood of rapid growth in a moist soil. . .	5 to 6 years.
"Id., wood free from splits, and grown slowly in a porous soil. . .	7 to 8 years.
"Magdeburg to Leipsic," and Austrian state railways.	7 to 8 years.
"Emperor Ferdinand" (Austria) and Western of Saxony.	8 years.

The line from Mons to Hautmont (worked by the Northern of France), laid down in 1858 upon half round sleepers in fir, at the end of 7 years had renewed 25 per cent of them, and probably would not have one remaining at the expiration of eight or nine years; this is nevertheless one of the most favourable examples of the use of fir in the natural state. Upon another portion of the same system, from Namur to Liege, the non-prepared triangular fir sleepers lasted seven years on an average; their duration might perhaps have been somewhat prolonged, but the instability arising from their form rendered it desirable, that they should be got rid of.

138. 3rdly Beech.—This wood, which, when suitably prepared, gives very favourable results, is one of the worst in its natural state; its alternate dryness and humidity cause it rapidly to decompose. Very rarely is it employed without being prepared.

It lasted in its natural state,

Upon the Brunswick railway.	2½ to 3 years.
In an experiment upon several thousands of sleepers between Bingen and Rolandseck, on the Rhenish railway.	3 years.

A portion of these sleepers, prepared by the Boucherie process, lasted no longer than the rest, they also became either rotten or completely split; but as the wood to begin with was too dry, to prepare it was evidently a mistake (156.)

139. 4thly Pine :

"Northern of Spain".	2 years.
"Grätz to Göflach".	2 to 4 years.
"Brunswick".	4 years.
"Oppeln to Tarnowitz".	4 years.
"Bavarian state railway".	5 to 6 years.
"Emperor Ferdinand" (Austria) "Magdeburg to Leipsic". . . .	6 years.

140. 5thly Larch (Larix).

"Bavaria.	Wood obtained from low valleys.	6 to 8 years.
	— — the mountains.	10 to 15 years.
"Grätz to Göflach"		9 to 10 years.

The great difference in the durability of the same material need occasion no surprise, when the numerous causes, which modify the properties of the wood itself, and the variable influence of the substance, in which it is placed, are taken into consideration; similar sleepers even last differently according to the nature of the ballast and to their use, whether in cutting, or in embankment.

141. If, instead of the temperate climate of central Europe, we turn to extreme ones, the conditions become much more unfavourable for the use of the same materials; this influence, which even in Spain is very decided, assumes intolerable proportions in low lying tropical regions.

In Brazil, for example, the pine of the country, very indifferent in itself it is true, could not be used. — In India the majority of timber is also destroyed with an equal rapidity beneath the influence of its climate, presenting the effects both of a scorching sun and of excessive rain; moreover the English engineers have there encountered a fresh difficulty, lessened, but only to a certain degree, by the resources afforded by the vegetation proper to these countries.

The woods employed in India are, not including creosoted fir, which is drawn from England;

1st The jarrah, and other woods of Australia; 2ndly Teak, iron wood; and 3rdly The timber of the country, principally from the west coast, and from the Himalayas.

The jarrah, the mahogany of Australia, is a very hard heavy wood, having a specific gravity of nearly 1.0; but it is liable to split under the action of the sun, to such a degree, that at the end of eighteen months upon an average at least 10 per cent has to be replaced; it resists the moist climate of Bengal better, than that of the presidencies of Madras, and Bombay.

In Scinde, the gumtree has been tried, but it splits while merely driving the spikes of the chairs; it would have been better in this case, to have used screws, but this does not appear to have been done.—This wood is besides extremely heavy, which is an advantage as regards stability, but an inconvenience for transport; all the more serious, that carriage is expensive, and the distances very long. — Notwithstanding the great specific gravity of the wood, one cannot materially reduce, either the cube, or, more especially, the breadth of the sleepers.

The Teak, less heavy (0.8), answers very well, but it is expensive. Upon the Indian Branch railway, it was tried in the form of balks serving especially as ties, and supported at each end upon a block of the same wood;

these supports, somewhat analogous to those of M. Pouillet in use several years ago upon the Northern of France, but now abandoned, cost only a fifth of the ordinary sleepers; but they had to be given up.

Iron-wood, the heaviest of all, has likewise lately been employed upon some parts of the East Indian line under similar conditions; that is to say, with a thickness only of from 3″ to 4″, being one half of that of fir sleepers; it is however doubted whether this will suffice to ensure a firm hold for the spikes.

Creosoted fir answers very well, both in the humid climate of Bengal, and in that of Scinde, which is much drier; its duration appears to be fifteen years at least.

§ III. — Preparation of sleepers.

142. The preparation of sleepers has been practised for many years: the preservative liquids in use are numerous, and the means of application are various, even under conditions otherwise identical; in other words, anthorities are not agreed, as to the relative value either of the one, or of the other.

The only points on which any definite knowledge exists are;

1st That oak when squared is not penetrated, at least under ordinary methods, by saline solutions.

2ndly That the core, or heart-wood, of the other kinds is in like manner impenetrable to them, as is that of oak itself.

3rdly That the durability of half round oak, as well as of the other materials in general use in Europe, whether squared or not (the larch alone excepted,) is almost always too limited to allow of their being employed in their natural state, even when their price is very low (136 etc.).

4thly That corrosive sublimate, creosote, or rather the thick oil given off at about 400° by the distillation of gas tar, and sulphate of copper, are the substances most efficacious in themselves, when introduced in sufficient quantities, and in such a manner, as to reach all the permeable wood; which they preserve more effectually than any other preparations do from destruction. This does not necessarily imply that they should preclude the use of any others, since the problem is exclusively one of economy, and a less efficacious method might in the end be more advantageous: the best in each particular case, being that method, which causes the least annual expense, including of course the renewal of the sleepers. But the uncertainty, which prevails upon the question of duration, even for one species of material, with a given fluid and mode of application, prevents any comparison of figures alone; for, with all these elements identical in each case, very different results may be arrived at according to the

amount of care bestowed upon the process. Each engineer judges naturally from his own observation; and thus may be explained, that difference of opinions upon a question of facts, which admit of no doubt, but still which are complex in themselves, and of which the causes are sometimes very difficult to assign.

The principles just laid down as deductions from experience appear to imply a contradiction : if in other substances, as well as in oak, the part alone next the bark is penetrable by the majority of the preparations, it would seem, that all woods were subject to the same conditions; and that all the rest, when squared, ought like oak to be impervious to the preservative fluids. If this is not the case, it is because, as has been already said (133), the hard wood, which occupies a great part of the section in round oak, and almost the whole, when squared and the edges taken off, is in the other kinds much smaller, and variable in size.

Some railways require, in the case of beech for example, that the heart wood shall not exceed a certain proportion of the whole; as this portion, untouched by the preservative fluid, and being thus less durable than the rest, may in fact become decomposed with impunity, unless it forms only a small kernel.

In the actual state of the question, it would be useless to insist at length upon isolated facts, the discussion of which could not lead to general results; we will therefore merely glance rapidly over the materials employed, the modes of application in use, and enumerate any facts, which may serve as a guide for selection in each case.

It is well known, that timber is composed essentially of cellulose, and of woody ternary substances, which are non-azotized; and that the vital fluid, the sap, contains quarternary azotized matter, the albumen and the fibrin, which rapidly decay, and with which the vegetable fibre is so to speak impregnated. The conditions, in which the sleepers are placed, are only too favourable to the mutual reaction of these elements and of those of the atmosphere, a reaction which constitutes putrefaction; moist woods containing in themselves two further agents in their decomposition; viz., water and air.

However unfavourable may be in general the situation of the sleepers, the wood escapes under this form, one cause of destruction, to which it is subject in many other circumstances, viz., the voracity of insects; the cryptogamic vegetation, which is therein developed, being rather the effect and the index, than the cause of its decomposition.

The preservative substances act, either in coagulating the azotized substances, thus rendering them incorruptible, or in forming with them fixed combinations; and probably also in destroying any fermentative elements, contained in the air.

Generally too, the mode of application eliminates, more or less completely, the sap, and consequently another cause of putrefaction.

148. *Antiseptics.* — Besides creosote, sulphate of copper, and bichloride of mercury, already mentioned, certain, other salts are used, especially chloride of zinc. Creosote is naturally in use in countries, rich in that kind of coal, which is suitable for the manufacture of lighting gas, in England it is almost exclusively used; its value is also sufficient to make its transport to a considerable distance worth the while, even as far as India has it been carried; the conveyance however in large masses of a material so inflammable has been abandoned on account of the danger which it presents; not to speak of the infecting effect upon the vessel, which it leaves behind it.

In France the very limited production, and consequent high price of this oil, restricts its use; it is the more expensive as it is very readily absorbed by the timber, and if supplied but sparingly the result is injurious.

The Belgian Government, having made trials of sulphate of copper, with but little satisfaction, in 1858 adopted creosote, which has afforded favourable results; the Eastern of Prussia Railway, and the majority of the German lines, bordering on the Rhine, also now prefer creosote.

It is however admitted, that this substance is ill adapted for fir with very open fibre, and but slightly resinous, as it absorbs it too freely; a sleeper of this kind might require as much as 13 or 15 gallons of oil, while an oak one, having but little of the soft part next under the bark, absorbs only 2 gallons. It is not necessary doubtless to saturate it completely, but the difficulty is where to stop; and thus it is, that a fir sleeper may in the end cost more, than one of oak, though its actual value is less.

Upon the Eastern of Prussia they use the tar iself, in addition to the thick oil obtained during its distillation; it is not however sufficiently fluid to penetrate deeply into the wood, with square oak sleepers its action extends very little below the surface.

In general the products comprised at present under the name of creosote are by no means constant, and frequently have nothing in common but their origin; for coal-tar is a mixture of a very complex kind, the nature and the proportions of the products extracted from it, varying with the nature of the coal, and with the manner of its distillation.

These products are divided essentially into, 1st light oils, or benzines, now used very commonly in the manufacture of dies; and 2ndly of thick oils, having their boiling point about 400°, and containing phenyle.

The efficacy of the oil of coal-tar, which in reality often contains not an atom of creosote, is owing, in addition to the oil itself, to the various elements, which it holds in suspension, and particularly to the phenyle; this oil has also the property, of little importance however in regard to sleepers, of removing the parasites, which attack the wood (*).

Sulphate of copper is nearly solely in use at present in France, it is also applied in Germany, and more particularly in Austria; it should be free from acid, and be perfectly pure; and it ought to be rejected, if it contain more than $\frac{1}{100}$ of sulphate of iron.

The employment of corrosive sublimate has always been very restricted, on account of its high price, and of the danger attending the use of so poisonous a substance, for some time back it has been almost abandoned: the Baden railway however made use of it, and can testify to its efficacy, some sleepers of oak, and also of fir, laid between Heidelberg and Manheim, were intact at the end of twenty years; though previously laid aside this line resumed the use of it again abandoned it, and recently it has once more adopted it, to the exclusion of every other method: this example has determined the Nassau railway to make a fresh trial of it.

Chloride of zinc is far from being as powerful an antiseptic, as the preceeding ones, but it is inexpensive; it has been little employed except in Germany, where it was, some dozen years ago, the preparation chiefly in favour. At the present time however it is little in use except upon the following lines, the Cologne and Minden, the Upper Silesia, (with fir), the Brunswick, and Nassau Railways, where it is employed conjointly with creosote, the Eastern of Saxony, and especially in Hanover, where it has been exclusively used since 1850; the engineers of that country claiming for it the property of completely penetrating the heart of the oak.

Chloride of manganese, which I saw employed in Austria in 1853, afforded unfavourable results.

Sulphate of iron, and sulphide of barium, successively introduced with a view to obtain, by double decomposition, a precipitate of sulphate of barytes encrusting the woody fibre, are equally abandoned; the non success of this experiment, tried in France upon the section from Creil to Compiegne, on the Northern railway, also upon the Eastern line (the price being 7^d each sleeper) may partly be explained no doubt by its complication, which would render it very expensive,

(*) According to recent observations, this property although it exists, is not so great as is often alleged, particularly in marine operations. The borer-worm, for example, avoids creosote more than it does sulphate of copper, but still it attacks it; so that the employment of creosote does not dispense completely with the use of nails with their heads fitting close together.

if all its indispensable conditions were complied with; and even these might perhaps be insufficient to ensure success.

144. *Methods of injection.* — The fluid may be introduced more or less completely,

1st By simple immersion in the cold bath.

2ndly By simple immersion in the warm bath, at a moderate temperature.

3rdly By simple immersion in the bath, at boiling point.

4thly By immersion when warm, the wood having first been dried and heated in a stove.

5thly In a close vessel, by the action of an artificial pressure, the wood being first exhausted of the air and water, which it contains; frequently also it has previously been submitted to the action of steam.

6thly By the method of Mr Boucherie.

It will suffice merely to mention the external applications in use. Marine-glue, obtained by adding a portion of gum-lac to a solution of caoutchouc in oil obtained from the distillation of gas-tar, was tried some twenty years since, but without success. Applied to very dry woods, free from splits, these applications would have no doubt a certain efficacy; but they are valueless, when applied to damp timber, which contains in itself all the elements necessary to the development of a putrifying fermentation. To coat such woods externally, whatever may be the nature of the application employed, is, as has been justly said, but "to shut up the wolf in the sheep-fold".

145. 1st *By simple cold immersion.* — In general it is but little effective; its action, caused partly by endosmose is very slow, as it requires two or three days, and sometimes more, for complete absorption to take place; a large quantity of receiving vessels are therefore required for the daily production of any quantity. This method was applied to half round oak sleepers on the Amiens and Boulogne Railway, but it was soon abandoned, the preserving fluid used being sulphate of copper; this process is however still used with pine and fir sleepers on the line from Berlin to Anhalt, on the Western of Saxony, and also on the Eastern of Saxony; on this last line they are immersed for a week.

It is also in a cold state, that corrosive sublimate is used in the duchy of Baden; the sleepers remain during ten days in the bath, which is in the proportion of $\frac{1}{150}$; the recipients are deal troughs, 20′ long, 8′·3″ wide, and 5′·0″ deep, coated inside with a mixture, composed of one part linseed oil, one part wax, two parts gum, and of oakum cut up into pieces; this composition is applied warm, it helps to cement the joints, if any leakage takes place; outside,

iron hoops and long bolts and nuts, sunk into the wood work, also serve to screw up the joints, and render them tight. The solution is made when hot, in a special vessel, 1 lb of salt, and 5 pints of water being only dissolved at one time, it is afterwards diluted to the proportion of $\frac{1}{150}$, by the addition of cold water; the preparation costs 3^d per foot cube, or about $\frac{1}{2}^d$ per gallon.

The workmen must adopt several precautions, the omission of which would cost them dear; they must carefully avoid all contact, either with the liquid itself, or with the prepared wood, and above all must be careful to prevent the introduction of any particle of the salt into the digestive, or the respiratory organs. The mixture is shaken up in a closed vessel, in order to dissolve it, into which the boiling water is first poured and then the salt, if the contrary was done, the steam would carry off the saline particles; the workmen ought to have a pad on their mouths. Before taking up the sleepers, the fluid is transferred by means of wooden pumps, into a neighbouring receiver; the men who take up the wood wear gloves, and a frock over their clothes; they ought besides to wash themselves with great care, especially before their meals.

Several manufactures require precautions of this kind, and in a permanent factory, with a special staff of workmen, it is easy to cause these prudential measures to be observed; it is not so however with temporary works, where the men are mostly from the place itself, and who scarcely understand that their very existence depends upon the tedious, and detailed execution of these recommendations; this constitutes a most serious objection against the application of this method, not to speak of its extreme slowness.

148. 2^{ndly} ***Warm immersion.***—It was ascertained on the line from Amiens to Boulogne, that by raising the sulphate of copper to the temperature of 140°, or thereabouts, in half an hour a result was obtained at least equal, all things else being the same, to that obtained by cold immersion for two days and even more; this expeditious and economical method cost from 3^d to 4^d per sleeper, the result also was satisfactory; the portion immediately beneath the bark having become as durable as the heart itself, which was all that could be expected; the liquid was in the proportion of $\frac{1}{56}$ of salt, and the operation was performed in a leaden boiler. The same method has been applied latterly, but with little success, upon the Eastern of France Railway with sulphate of copper, at a cost of 5^d per sleeper; at present however it is but little used, and seems best adapted for half round oak sleepers, where its duration, is necessarily limited by that of the heart-wood itself, forming as it does so great a proportion of the whole mass. The Orleans line still uses this method, even with squared oak; the bath consists of sulphate of copper in the proportion of $\frac{1}{80}$, heated to 140°, it does

not however penetrate any great depth; but as it costs very little, and as it is on the surface that it acts upon the wood, the limited action of the preserving matter is looked upon rather as an advantage. Its application is too recent, only since 1856, to judge of its efficacy; but looking at the results, as stated by Mr Sevene, chief engineer of the permanent way, it acts well.

147. 3rdly *Immersion in the bath at boiling point.* — This method ("das Kochen", Büttner process) has been applied in Germany, especially in Bavaria, where it was in favour a few years ago; the sleepers, squared fir, being placed vertically in a large deal trough, are fixed at the top to hinder them from floating; the fluid, sulphate of copper, is then introduced and raised to the boiling point by means of a steam jet, carried from a small boiler, the injection of steam lasts for 45 minutes; it is then left to cool slowly, and it is during this time especially that absorption takes place.

This method has generally given very indifferent results. A moderate rise in the temperature no doubt increases the absorption, but in this case the increase is excessive; for, although by this means a greater dose of the preserving substance is introduced, yet the very high temperature of the solution alters the constitution of the wood, taking from it elements which are essential to its preservation.

In Prussia, it is urged, that by this method the surface only is penetrated, perhaps however the sleepers were taken out of the bath too soon: this process is nevertheless still in vogue on the Eastern of Saxony line, and it has been applied also to beech, and to a small quantity of oak sleepers on the Holstein lines; in both cases chloride of zinc was used, at a maximum temperature of 185°.

148. 4thly *Immersion in warm bath after heating the wood in a stove.* — With the exception of the "Boucherie" process, which in this particular is under conditions special to itself (156), it is generally necessary, in order to prepare the wood to absorb the preservative fluid, previously to expel as far as possible all the air and water it contains. A lengthened exposure to the air effects the first object, particularly if it has previously been for some time immersed in water; the effect of this being, that the water takes the place of the sap, displacing at the same time various humid substances, which tend to cause putrefaction; thus facilitating dessication by subsequent exposure to the air. Heating in the stove evaporates the water, and expands the air, which is in great part expelled from the passages in the wood, which while still warm is plunged in the hot bath and becoming saturated more quickly, absorbs all the more; the heat must however be applied by degrees in the stove, lest the wood might split.

This heating in a stove, and immersion in a warm bath, applied especially with creosote, constitutes one of Mr Bethell's methods much used in England; it is also employed in Germany on the line from Aix-la-Chapelle to Dusseldorf.

The sleepers, half round, and without bark, are heated in a stove for from 24 to 48 hours, at a temperature of 212°, they are then immersed in the oil bath for 24 hours : the cost is about 10 ½d per sleeper.

Mr Bethell also makes use of the following process ; the sleepers whilst drying are exposed to the gases and other products of combustion, with which they become impregnated; they are then plunged into boiling oil. This method gave very indifferent results on the Eastern of France Railway, where however it was not properly applied.

149. 5thly *By means of a vacuum, and by pressure.*—As the method by means of a closed vessel requires a considerable amount of plant, it does not answer for a small quantity; but as it succeeds the better in proportion as the wood is dry, the operation may be performed at some central point, whither the timber can be brought from the distant parts; it thus becomes only a question of carriage.

The implements required are; 1st A receiving vessel; being a long cylindrical boiler, having at one end a spherical top and at the other a cover solidly fastened to it, and capable of supporting, as must also the receiver, a pressure of 100lbs, and even 130lbs per square inch. 2ndly Small waggons, upon which the sleepers are piled up, running on small rails, laid both inside the vessel and out, so as to facilitate their loading and unloading. 3rdly A steam engine and its boiler, generally a moveable one. 4thly Air pumps. 5thly Force pumps. 6thly The tubes, and taps necessary to establish, or to interrupt the communication between the various parts.

The waggons being run inside, and the cover put on, the receiving vessel is put successively in communication; 1st with the boiler, so as to receive from it a jet-of steam, 2ndly with the air-pumps, to create a vacuum, 3rdly with the vase open to the air containing the fluid, which is forced by atmospheric pressure into the receiver, 4thly with the force pumps, which regulate the pressure of the whole.

It is said, that, as by this method the fluid is introduced in every direction, it has the inconvenience of as it were imprisoning within the wood certain baneful gases, and liquids, which do harm either by their own nature, or merely by the obstacle, which they present to the introduction of the preserving fluid; this objection, though correct in principle, loses much of its weight, if the three first stages of the operation have been conducted so as to effect their object, which is to expel the air and water contained in the wood.

With this method the three fluids the most commonly in use are applicable to penetrate the sleepers; viz., creosote, chloride of zinc, and sulphate of copper; but with the first, the action of the steam upon the wood must be replaced by a previous dessication, as the presence of water, even in a very small proportion is an obstacle to the penetration of the oil. Besides it is indispensable, that this substance should be heated in the receiving vessel, whenever the temperature of the air is low, in order to keep it in a fluid state, so that the tubes may continue to inject the steam, though only after the introduction of the liquor. This action of the steam is always advantageous, it is often even used in the receiver which is open to the air; the heating however requires to be done in moderation, or else there would be a loss in distillation.

With the two first named fluids the receiving vessels are of iron, with the third it must be of copper; it is in fact this considerable item of expense, and the necessity, in order to continue working without intermission, to have two sets of receivers, which alone has limited the application of sulphate of copper. Since 1853 it has been in vogue in Austria; in France also the method of Messrs Légé and Pironnet, is nothing else, the details are well understood, but the principle had nothing new in it.

Attempts have been made with sulphate of copper to preserve the sheet iron receiving vessel by protecting it on the inside by a lining, or with cement. Mr Bethell, who used both the air-pump and sulphate of copper, tried lead, india-rubber, gutta-percha, and a mixture of gutta-percha and of india-rubber; this layer of composition being protected by a wooden covering. Messrs Burth and Co. in the apparatus they have erected at Bordeaux, and also at Hennebon, made use of a layer of bitumen covered with a lining of wood. Experience does not appear as yet to have decided upon the merit of these various expedients. In the small waggons which are used, the portions generally made of iron ought besides in this case to be replaced by copper.

150. It is quite evident, that the pneumatic method affords results the more satisfactory, in proportion as the preliminary action of the steam is prolonged, and as those of exhaustion and of compression are extended. This lengthened action is all the more costly in consequence of its causing a greater absorption of the preserving matter: the exact length of the operation must be regulated by the relative cost of the timber, and of the quantity of the fluid necessary to lengthen its durability, and varies of course with the price of the two articles. This it not however sufficient to explain the great differences which exist in the results, and which may somewhat be understood by the absence of any precise data as to the degree of efficacy, that we may expect; the greater results we look

forward to from the fluid, the less ought we to diminish the expenses of preparation.

151. *Creosote.* — The application of it by the pneumatic process has been made on the Eastern of Prussia, and on the Upper Silesia Railway; substituting, as must necessarily be the case (148), for the preliminary operation of the steam jet into the receiver, the previous dessiccation of the wood, either in the open air, or in a stove, where it remained until it had ceased to give off any gas; the sleepers were then passed into the receiving vessels.

At Bromberg, on the Eastern of Prussia line, the sleepers, oak and fir, are kept piled up for a year, or a year and a half, before being injected. If the stacks are under shelter, the sleepers are so completely dried by the end of this time, that any heating in a stove is unnecessary; but if however they have not been so situated, this operation is still required, especially if their preparation takes place shortly after continuous rains. Four hours on an average is the time for heating them in the stove; the process of exhausting, with the mercury standing at 24 to 26 inches, lasts one hour and a half; and the compressive one, with a pressure of from 100^{lbs} to 115^{lbs} per square inch, for $2\frac{1}{2}$ hours. The mean absorption of oil by fir sleepers is 42^{lbs}, and only 11^{lbs} by oak ones; indeed fir ones have been known to absorb as much as 154^{lbs}, whilst with oak $18\frac{1}{2}^{lbs}$ has been the maximum : in practice therefore there is a wide difference between their powers of saturation.

At Bromberg they use 1^{st} fine oil, procured from England, 2^{ndly} middling oil, 3^{rdly} tar, from the gas-works at Berlin.

The cost of the injection of a single sleeper is;

	Fir.	Oak.
With fine oil.	$3^s\ 0^d$	11^d
With middling.	$1^s 11^d$	8^d
With tar.	9^d	$4\frac{1}{2}^d$

The fir sleepers were completely penetrated by the oil, with the exception of the heart-wood; in the squared oak ones the cracks and splits only were filled with it.

On the Upper Silesia Railway the sleepers were submitted successively during 30 minutes to the vacuum, with the mercury at 20 inches; and then for 45 minutes, the liquid was injected under a pressure of 83^{lbs} per square inch. The price allowed to the contractor per sleeper was $1^s\ 3\frac{1}{2}^d$ for oak sleepers; and $2^s\ 3^d$ for fir ones, as they absorb much more oil.

Since 1858 the application of creosote in a closed receiver has been applied, on the State Railway in Belgium, to fir sleepers, and with success, as far as one

can judge; the quantity of oil absorbed is not more, than from 1 ½ to 2 gallons; and the price is $1^s\ 3^d$ per sleeper.

152. *Sulphate of copper.* — The same method, but without the previous drying in the stove, has been applied in Belgium to red pine from the North, which can be easily procured. According to Mr Coisne, Inspector on the State Railway (*), this wood, when in a very dry condition, can be penetrated even to the heart; beech and hornbeam are still more easily, and more uniformly saturated, white pine is much more difficult of penetration. The red pine sleeper retains only about 4 ½ gals of oil, even after the exudation; about 3 pints on an average, which is caused by the reaction, that takes place after the pressure is removed, and which continues about two days.

Mr Coisne gives the following prices:

	Price.	Duration	Annual Cost.
Oak.	$5^s\ 3^d$	12 years	7^d
Pine with about 2 gals of oil.	$4^s\ 3^d$	10 »	$6\frac{1}{2}^d$
Pine with from 4 to 5 gals (saturated).	$5^s\ 3^d$	15 »	6^d

The vacuum is produced with the mercury standing at from 20 to 22 inches; and the pressure from 115 to 145 pounds per square inch.

The timber ought to be dried for 8 or 10 months in stack-yards, and after being prepared, placed under shelter until required.

The Orleans Railway since 1861 use pine sleepers from the Landes (pinus maritimus), prepared with sulphate of copper by exhaustion and compression. It is not possible as yet to form an opinion as to their durability; up to the present time however no symptoms of decay have appeared.

153. As by this method only wood, which is very dry is operated upon, and consequently where the antiseptic fluid cannot take the place of any liquid previously contained in the wood, the augmentation in the weight of the sleeper gives the actual quantity absorbed, whether of oil, or of saline solution; to ascertain however the increase satisfactorily a large number of sleepers ought each to be weighed. This method of verification is therefore difficult in practice, and the result, even when attained, would be immaterial; the important point being not to ascertain the amount absorbed, but whether the penetration has been uniform.

Some lines in their specifications require special experiments to be made on this point; on the Orleans Railway, for example, with each operation must be

(*) "*Annales des travaux publics de Belgique,*" 1864, p. 193.

included two trial balks, one twice the length, and the other double the thickness of the sleepers : the two are afterwards sawn down the middle, the one lengthways, the other across; thus showing at once the amount of penetration which has taken place. With sulphate of copper this examination requires a special method; the presence of the colour produced by the yellow prussiate of potassa (Ferrocyanide of potassium) is made the test, in the absence of chemical analysis, which though stipulated in the purchase is but little used. A solution of 3 ounces of prussiate in $1\frac{3}{4}$ pints of water, and spread with a brush upon the wood, ought to give a decided red colour; a pink tint shows, that the penetration is not complete; an experienced eye does not require this test, merely a careful examination of the sides of the wood will be sufficient. If the two pieces on trial have been well injected, all the sleepers in that operation are received; if on the contrary the trial piece is faulty they are rejected, but only provisionally, for they may be submitted to a fresh test, with other witnesses.

The physical condition and quality of wood of the same kind are so variable, as to render one very cautious in the selection of these witnesses; for though the preparation may be good, the test pieces may show the contrary, and the opposite may take place, for the contractor generally chooses balks, that are porous and very dry, as test ones. This method of test is not in general use, it is generally preferred to bore a hole in a certain number of sleepers; again those that have been found faulty during the trial, have by this fact undergone a certain depreciation in value, which leads to disputes.

The pneumatic process, when applied to sleepers, cut to their definitive length, has no simple and certain means of control, which is a great objection. Taking everything into consideration it would be better to have the balks of such a size as to require cutting, both lengthways and crossways, as in Mr Boucherie's process; yet again, without mentioning the difficulties of working, and of carriage, the large size of these timbers would almost preclude their complete penetration.

154. ***Method by slow, but prolonged pressure.*** — On the Berlin and Hamburg line during the injection of sulphate of copper in closed vessels an attempt was made to substitute, for a diminution in the intensity of the pressure, an increase in its duration; the former did not exceed 14lbs per square inch, but it was maintained for 5 or 6 hours, the sleepers often remaining all night in the bath, though free from pressure. This trial did not give satisfactory results; it invariably reduced the power of product on of an expensive appa-

ratus; the strength of the fluid, which was at first $\frac{1}{40}$ was reduced to $\frac{1}{80}$ then to $\frac{1}{100}$: the expense of the operation however is not costly.

Intermediate sleepers cost.	4^d	each
Joint » »	7^d	»

A similar method has been adopted on the Magdeburg and Wittenberg line; the pressure is limited to 21^{lbs} per square inch, which was produced by 48 feet of head of water; and it was continued for from 6 to 8 hours.

155. *Chloride of zinc.* The solution of chloride of zinc employed in Hanover is in the proportion of $\frac{1}{60}$, with a pressure of 115^{lbs} per square inch.

Cost of preparing an intermediate sleeper, interest, and wear of plant included, was.	Beech.	6^d
	Fir.	4^d
	Oak.	3^d

On the Cologne and Minden line, where chloride of zinc is used with the same method, the prices respectively were 10^d, $1^s\,2^d$, and $6\frac{1}{2}^d$; on the upper Silesia Railway, this method being much employed, the preparation of fir comes to 9^d, which is a mean price between the above 4^d and $1^s\,2^d$; the great difference being due to several causes, amongst others no doubt to the shortness of the duration of the application, as used in Hanover.

In fact the operation is very long at the Kattowitz works on the Upper Silesia line; the action of the steam is kept up for from 2 to 6 hours, according to the degree of hardness, and dampness of the wood; the vacuum is maintained for 30 minutes only; but the pressure is carried up to 100^{lbs}, and is kept on for from 2 to 6 hours, the specific gravity of the liquid being about 1.026 (3 degrees Baumé); the whole operation lasts six hours for fir if very dry, and twelve if it is damp. Under these conditions wood dried in the open air absorbs more liquor, than does the damp, but then the latter is more uniformly penetrated; a well prepared sleeper ought to absorb 70 to 80^{lbs} of liquor, and even sometimes as much as 100^{lbs}.

156. *Mr Boucherie's method.* — This is undoubtedly the most consistent method of them all. The fluid with a slight pressure upon it penetrates the wood at one end only; and entering it travels through its whole length, driving before it the sap and air, and filling up their place.

The operation can however only be performed with uncut, round timber, recently felled, and with the bark still on, unless it has been only just cut down. The preliminary process of drying, which is so favourable to absorption in the other methods, especially when the liquor is insoluble in water, such as the tar oil, is

on the contrary nearly a fatal obstacle to the success of the Boucherie method; as the aqueous solution of sulphate of copper is not able under the reduced pressure, which is one of the characteristics of this method, to penetrate the woody tissue unless it be damp, and still full of sap. The centre, or heart, where the cellular form is so lost as almost to prevent the circulation of the sap, is from the same reason excluded from the benefit of the action of the fluid; but as we have seen, the other methods also fail in this respect, excepting only perhaps tar-oil.

All woods, except oak, that have an impenetrable centre, are rejected, unless this form but a small proportion of each; on the Eastern of France Railway indeed all wood with a heart may be entirely rejected, by the specification for the supply of beech and hornbeam sleepers, to be prepared by the Boucherie method.

"As the heart of the wood is impenetrable to the preservative fluid, and also is "subject to decay rapidly, when in the ground, all sleepers containing any will be "rejected."

Knots also being obstacles to complete penetration, may likewise be a cause for rejection; all wood not perfectly sound, and especially such as has been heated, no matter in what manner, must necessarily be rejected.

Mr Boucherie has adopted for the strength of his solution $\frac{1}{67}$ (1^{lb} nearly per $6\frac{1}{2}^{gals}$), with a pressure of about 14^{lbs} per square inch; which is obtained by erecting on a scaffolding about 10 yards high the vats A, which contain the liquor (Pl. XIII, figs. 1 and 2). A leaden, or copper pipe *t*, *t*, *t*, leading from the vats, and running perpendicularly down under where the timber is to be prepared, and already laid on the ground, distributes the fluid to each by means of a small india rubber pipe *c*, *c*, ending in a small cylindrical reservoir; of which the depth is optional, but it must be at the bottom nearly as broad as the whole cross section of the log, since it ought to represent the section of flow of liquid into it from the timber. The construction of this small reservoir was one of those problems, which are simple in appearance, but prove difficult in reality, and that are often met with in works; and in the solution of which, according as it is simple, or complicated, much ingenuity, or the contrary, may in practice be displayed: in this instance it is characterized by that simplicity in working, which is indispensable for the success of the process.

For timber, such as telegraph posts, which has not to be cut up before being used, and for such sleepers as have to undergo a second operation, as is frequently the case (159), the reservoir is made of a circular wooden disc, fixed by a screw placed in the direction of the length of the timbers,

griping, under the pressure of the screw, a tress of hemp (fig. 10) thickened in the middle, which is placed round the edge of the disc and forms the side of this small reservoir : the screw may with advantage be replaced by three hook-bolts, *b*, *b*, *b*, which tighten up the disc by means of a small triangular frame, ABC (figs. 12, 13 and 14.)

For sleepers, the balks, being of a double length, have the reservoir in the middle (figs. 2, 15 and 16); a sawcut is here made across them leaving but a small circular portion in the centre uncut, the sides of which by the insertion of a small wedge are caused to open out, to allow of the hempen tress being inserted; the wedge is then withdrawn, and by means of the elasticity of the fibres of the wood the sides close up and press upon the tress; a small wooden pipe α (fig. 3), having its upper end *e* fixed in the flexible tube *c*, is then inserted into a slightly inclined gimlet hole.

Very soon after the communication with the vats is thus established the sap begins to appear at the free end, or even at both ends of the piece of wood; in about an hour at latest it becomes mingled with the sulphate of copper, and soon the latter predominates : but as the resistance of the wood to penetration is not uniform, the operation is continued, although the liquor may come out quite pure; so that it often lasts from 48 to 60 hours, for the ordinary kinds, viz., beech and hornbeam.

Mr Boucherie selected, and it has been the quantity generally adopted about $\frac{1}{3}$ lb of salt per foot cube, as the average amount of absorption by beech.

It is difficult to ascertain exactly if this quantity has been attained; but by the very nature of the operation it is easy to tell, by examining the inside, when exposed to view, whether the salt has penetrated (the core of course excepted) every part of the sleepers, which can be seen by sawing them diametrically across. The red colour given by the yellow prussiate of potassa is here also the usual means of test; for pieces which are not cut up, the trial ought to be made at the end from which the liquor flows out, and at a depth of at least half an inch.

157. This method of preparing sleepers has given very good results, but it has also afforded very bad ones; this it has in common with other methods, though with it the occurrence of the extremes of difference may occur less often.

On the Namur and Liege line triangular fir sleepers, not prepared, were in 1860 replaced by prepared beech ones; in 5 years a proportion of 5 per cent had been renewed, and their mean duration will not probably exceed 8 or 10 years.

The Belgian State Railway (143) has completely abandoned the Boucherie

process; as all the sleepers, of beech or hornbeam, to which it had been applied, lasted but 5 or 6 years.

In opposition to these examples, which might easily be multiplied, may be adduced others not less numerous, proving the very great value of the process, when applied with care : in general it ought not to be contracted for, but performed by the parties themselves, under the superintendance of a careful and trustworthy inspector; any guarantee would in this case be difficult, as thereby the settlement of accounts would be much postponed, the more so that it is even still hard to define, what is a good preparation, and what is not.

The uncertainty is not as to its possible effectiveness, but as to the point to which in practice it may be carried; the proportionately high price of the mixture, and the necessity of operating on wood recently felled, and not split up, have hindered the Boucherie process from receiving, as extended an application as might be expected from the success, obtained in France some time back, and which is so well acknowledged; its employment at present being restricted to railways which run near to forests of beech. Owing to the necessary loss of wood, in cutting off the sides of the round log when transformed into a square sleeper, the price is thereby raised, and this increase is again augmented by the loss of salt, which it is difficult to avoid during the lengthened circulation of the liquor; even though the overflow from the ends, as well as the leakage which takes place in the middle, are again returned to the vats.

158. The details of the method of application often vary, according to the nature of the wood, the price of the workmanship, etc.; for example, the following is the process pursued in 1863 at some well conducted works at Orawitza, in Hungary, for the preparation of beech sleepers for the lines belonging to the Austrian Company. The operation comprises three stages.

1st The injection of a fluid which, under ordinary circumstances, is in the proportion of $\frac{1}{67}$.

2nd The injection of a more diluted fluid $\frac{1}{100}$, continued until it flows out from the wood at the same strength;

3rd The injection of pure water, in order to wash out any excess of salt, which not having entered into combination with the wood would not only be useless, but even hurtful; either by crystallizing, and thus causing the wood to split, or by attacking the iron spikes, which however one would think might be sufficiently protected by being galvanized, or tarred.

The operation lasts 72 hours altogether, of which 2 only are devoted to washing out.

The liquid, which comes from the wood after the expulsion of the sap,

is filtered before being returned to the reservoir on a layer of oxide of copper, 12" thick, in order to neutralize the sulphuric acid set free by the organic combinations into which copper has entered; at the same time the liquid is cleared of a part of the impurities, which it has acquired by being mixed up with the sap.

159. Upon the Eastern of France Railway the sleepers generally undergo a double operation, all the logs according to the specification ought to be successively injected from each end : Mr Guillaume, engineer of the Permanent Way on that line, assigns the following reason for so doing :

"While allowing entirely the utility of the first operation applied to all logs, the in-
" jection by means of a sawcut in the middle of a log of double length, it is often
" found however that this is not sufficient; for the sap bearing channels of the upward
" branches, which issue from the trunk nearer to the root than the sawcut, do not
" receive the antiseptic liquid, as they grow in the opposite direction (Pl. XIII, *fig.* 17);
" again the parts near the core, although penetrable, sometimes offer great resistance
" to the liquid, which percolates in preference through the younger wood, less close
" in texture than the other. It is therefore better on this account to repeat the operation
" upon the timber, introducing the liquid by the other, or lower ends, which can only
" be done by means of circular discs; these need only be as large as the centre of the
" log, if the object of this second operation is to remedy the unequal amount of pene-
" tration of the soft portion under the bark, and of the closer part, or white-heart,
" which separates it sometimes from the core proper.
" Experience has proved, that in the majority of cases, it is necessary to operate
" as above described, and therefore it is that article 7 of our specifications is made a
" general obligation; when however the wood presents any exceptional qualities, and
" that a simple injection is shown to be sufficient, the inspectors are authorized not to
" exact the repetition of the process; this however is quite an exception."

160. Mr Pontzen an engineer on the Southern of Austria Railway has been induced by a careful examination of the pneumatic, and of the Boucherie processes, to propose a mixed method (*), by which he seeks to unite the advantages belonging to the two. From Mr Boucherie he borrows the close-jointed discs used for telegraphic posts, but reverses their action; the small aperture being no longer used to introduce the liquid, but to take off the pressure at the end of the log to which the disc is applied. The liquid penetrates by the other sides, and, as in Mr Boucherie's method, causes a current which passes off outside the small reservoir by means of a pipe adapted to each disc; all the pipes unite into one, which passes through the obturator of the receiving vessel, and discharges into the open air.

(*) "*New method of preserving timber,*" Vienna, 1863.

This combination of the two methods is ingenious; but there is evidently some difficulty in carrying it out. As the idea has not yet been put into execution, we shall not dwell any longer on the subject, which however deserved mentioning.

161. In the United States a Company has been formed for carrying out Robbin's Patent, by which the wood is submitted to the action of the fluid, when in the state of steam. A large retort of wrought iron containing coal tar is placed on a furnace, and communicates by its double-branched neck, each furnished with a tap, with two chambers, in which the sleepers are piled upon small waggons; each chamber is used alternately to prevent interruption in the process. The temperature of these chambers ought to be 300° Fahrenheit; the first effect of the heat is to expel the water, and the air contained in the wood: though it is admitted that the oil penetrates much more easily as a vapour, than in the liquid state, it is not probable that this species of fumigation can be so efficacious, as the pneumatic process when properly applied.

162. *Drying the sleepers by charring the outside.*—To char wood externally, as a preventive against putrefaction when embedded in the soil, is no new expedient. The charring process invented by Mr de Lapparent, a shipbuilder, for purifying ships, and preserving their hulls, is nothing else but superficial torrefaction, but rendered so as to be applicable in practice to wood placed under the most opposite conditions. It appears that Mr de Lapparent's idea, though it has at certain ports been received with the favour it justly merited, yet seems to inspire a dread of causing fire in the purification of ships; in the French Imperial navy however it seems to be universally used with new vessels, as well as with those which are altered.

The author, naturally seeking to extend the field of his operation, could not fail to perceive the rapid decay of railway sleepers, and the want of any easy and economical method, which should ensure their preservation.

Mr de Lapparent's method consists in charring the wood by means of a jet of gas through a blowpipe.

" Three principal effects " says Mr Payen (*) " are produced: 1st The surfaces still " damp from being washed are quickly dried by the almost instantaneous evapora- " tion of the superficial moisture. 2nd All organic matters liable to decay, as well as

(*) " *On the purification of vessels and the preservation of timber,*" *In the* " *Annales du Conservatoire des Arts et Métiers.* " 1865, p. 357.

" microscopic animals, animalcules, and cryptogamic plants, undergo a degree of " heat, and even a partial combustion, which destroys all vitality, as well as all tendency to fermentation. 3rd The woody fibre itself at this high temperature is to a " slight depth partially distilled, disengaging the ordinary products arising from the " distillation of wood; especially acetic acid, creosote, and several carburets of hydrogen, in fact tarry matters containing the most powerful antiseptic properties. " Thus while destroying all fermentation, and decaying organic substances, the woody " fibre is at the same time impregnated with the tarry antiseptic products, which " assist greatly in the preservation of the timber. "

The wood is thus armed with a species of coating against exterior decomposing causes, but it is left completely free to the action of all internal ones; so that the effectiveness of the process depends on the relative activity of the one, and of the other. If applied to wood rather too soon, one might even dread that in certain cases, as with painting, more harm than good might be done: but several long trials prove that this fear has no foundation.

Mr de Lapparent naturally enters more fully into details than Mr Payen does, upon the effects of the method, complex in themselves, and which he has analyzed with great care; he lays particular stress upon the action exercised upon the surface.

" All inquiries for the preservation of wood (*) resolve themselves into finding a " means of neutralising the action of those elements, which determine, or accelerate " their decomposition.

" The method the most in use endeavours to abstract the sides of the wood from " contact with the air; this result may be obtained by giving them a coat of paint, but " its use requires certain precaution, which if neglected would be productive of more " harm than good, as is the case if applied to wood which is still damp. "

The author explains in the following words the action of external charring (**).

" In the first place, under the action of a jet of flame raised to a temperature of " from 1800° to 2200°, the outside of the wood to a very perceptible depth was completely dried.

" Now, when the outside faces have been deprived of all the watery sap contained " in them, that which remains in the inside of the wood does not seek to enter into " them, but endeavours to find an exit by means of the longitudinal channels and " fibres.

" I have already declared, and I repeat it here, that it is the outside of the wood, " which it is especially necessary to bring to a state of complete desiccation.

" The general opinion entertained is, that in preparing wood the entire mass should

(*) " *Conservation des bois par la carbonisation de leurs faces,* " in-8°, p. 8, Paris, 1866. Arthus Bertrand.

(**) *Work just quoted*, p. 9.

" be thoroughly dried; a closer examination of the question, however, has greatly " changed my ideas in this matter. I believe the conclusion has been come to " too hastily, that, because the outside surfaces of fresh wood in contact with one " another, show signs of rottenness, therefore the inside is in the same condition.

" For who is not aware of the fact, that timber totally immersed in water is pre- " served, so to say, indefinitely? which is caused by its being entirely removed from " contact with the air. It is only when the fibres and cells are left empty by continued " dryness, that the air can penetrate and introduce with it the elements of fermenta- " tion with which it is charged."

" The second effect (*) of the jet is the destruction of all those germs, which waft- " ed by the air, may have penetrated and accumulated, as if by a kind of filtration, " in the outer surface of the wood.

" In the third place, the body of flame diffuses over the surface of the wood a thin " layer of completely carbonized matter, which rests immediately upon another " which is simply torrefied; that is to say, which has only received the quantity of " heat necessary for distilling the wood, and the crust of which is found in conse- " quence impregnated with the products of this distillation. These products are them- " selves antiseptics, and besides, in all cases, the carbonized layer would not allow " the action of fermentation to be propagated.

" Finally the flame shrivels up and hardens the exterior of the wood very consider- " ably, and by this alone renders it much less exposed to the action of exterior " agencies."

Even admitting the ideas of the author, who has studied the question closely, it does not appear that his process can be as efficacious, as those which penetrate into the mass itself of permeable tissue, and neutralize therein all decomposing agents.

Mr de Lapparent it is true disputes the durability of their effects. " This preparation," says he, speaking of the Boucherie process, " does not last, when the wood is immersed in water, or simply exposed to the action of the rain." As to preparations with creosote, he says, " their efficacy depends upon a volatile substance, which they lose at the end of a certain time, and become merely an inert covering."

The author also denies the fact generally admitted of the formation of compounds, which are stable and insoluble under the influence of antiseptics; a fact which appears established however by long and numerous observations.

High cost, and irregularity in their results, may sometimes be objected to in the ordinary processes in use; but their efficacy, when they are applied with due care, is beyond all dispute.

Mr de Lapparent was not long before he substituted for the coal-gas blow-

(*) " Conservation des bois par la carbonisation de leurs faces," page 11.

pipe, when charring separate pieces of timber, a method more simple and economical, copied from the enameller's lamp; and which he called the blow-pipe lamp. Mr Hugon, director of the compressed-gas works at Paris, next constructed a generator of a fanned flame, which Mr de Lapparent completely approved of.

As it is in this shape, that the principle is at present applied to sleepers, it will suffice therefore to summarily describe the blow-pipe of Mr Hugon.

The apparatus (Pl. VII, fig. 13) consists of,

1st A furnace F, containing the combustible (burning coal), having a feeding door P; and an orifice A, forming the mouth of the blow-pipe.

This furnace is supported by a column C, penetrating down into the frame; and by means of which the furnace may be raised or lowered by a balanced lever L, and also may be made to turn round the column vertically.

2nd A double-acting bellows S, pumping air into a chamber R, and thence through an india-rubber tube T, into the lower part of the combustible matter.

3rd A reservoir of water, ρ, provided with taps, with which the injection of water, which mixes with the air in the pipe, a, is regulated.

4th A wooden frame s, carrying the rollers r, on which the sleeper to be charred, t, is placed, and worked along.

To start the apparatus, some shavings are placed in the bottom of the furnace, and coal put upon them; when the mass has completely caught fire, the upper and lower apertures, which at first remained open to cause a draught, are closed, the bellows is then put in motion, and a volume of flame, issues from the mouth. When the coal has become transformed into coke, the tap for the injection of the water is opened, in order to replace for the production of the flame those volatile elements, which were at first furnished by the coal. A jet of water is introduced into the furnace at each stroke of the piston; and, being composed of hydrogen and carbonic acid, the latter is decomposed by the incandescent coke into oxide of carbon, which is burned, as well as the hydrogen, either by the injected air, or by the external atmosphere outside the mouth. Mr de Lapparent however considers, that this addition is not an indispensable one.

Many of these apparatus are in operation on several parts of the Orleans Railway; where the majority of the oak sleepers are prepared by them. The beech sleepers are prepared by the Boucherie method; some thousands of them however, after undergoing this process, have been also submitted for experiment to the action of charring.

The average price comes to $1\frac{1}{2}$d. a sleeper, not including general expenses. As the charring does not cause any fresh cracks, or splits, nor increase those

which exist, it is likely that the result obtained will well justify so small an outlay : as squared oak resists almost entirely, the penetration of preserving substances, it is easily understood, how the engineers of the Orleans Railway, did not hesitate to apply carbonization to it on a large scale.

It would even be interesting to make the experiment on other kinds of timber in an unprepared state.

§ III. — Durability of prepared sleepers.

163. *Creosote.* — The long experience of English railways has given evidence of the efficacy of creosote; that is, when it is genuine, and when the operation has been properly performed. Sleepers of red and yellow pine, fir, etc., laid down more than a quarter of a century, are still perfectly sound on the Great Northern, Eastern Counties, the Stockton and Darlington line, and others. Well creosoted sleepers are only replaced through splits caused either by the nature of the wood itself, or during the driving of the spikes, or in consequence of the destruction of the wood underneath the chairs. The efficacy of the process is therefore absolute, since it completely destroys all chemical action; so that the duration of the wood, is only limited by its resistance to mechanical action, and which resistance this injection does not appear materially to affect.

It however seems, that a partial reaction is taking place against creosote; the virtue of which has been, until now, undisputed in England. According to a special report (*), with which meanwhile we leave the responsibility of the assertion, the Midland Company were abandoning creosote, because it prolonged by four years only, sleepers which on this line last at least sixteen years in a natural state. But, as this figure sufficiently indicates it can only be a question here of oak sleepers, and consequently of a case peculiar to England alone (**).

Perhaps the method of preparation, and the quality of the tar adopted were not without some fault.

164. *Sulphate of Copper.* — Sleepers prepared with this substance required renewing at the following rates.

(*) " Engineering, " 1866. N° 20, page 47.

(**) The figure, 15 years, indicated above (141) according to several engineers, as the probable duration of creosoted Baltic fir on the Indian railways, is disputed by other engineers. Mr Danvers (Report on Indian railways in 1862-63) reduces it even to 5 years, the same as for the native woods.

However great the difference is, it may be explained, up to a certain point, by the degree of absorption, which is very variable, especially with creosote.

1st. *Fir*, at the end of eight years : 1° 4.73 per cent on the Berlin to Potsdam and Magdeburg line; 2° 3.82 on the Eastern of Prussia; 3° 3.00 on the Magdeburg and Wittenberg line. On the Upper Silesia Railway it reached 51 per cent. In spite of this last figure, due undoubtedly to some accidental cause on this line, 12 years is the general average duration there.

2nd. *Pine*, at the end of seven years; 31 per cent on the Aix la Chapelle and Dusseldorf line.

3rd. *Beech*, at the end of nine years; 97 per cent on the same line.

According to a report of the Directors of the Westphalian Railway, the application of sulphate of copper does not much prolong the duration of squared oak; which is quite easy to understand. The Berlin and Hamburg line concluded, after an experience of 20 years, that squared oak, unprepared, and fir prepared with sulphate of copper have an equal duration, viz., of about fourteen years.

The Berlin Potsdam and Magdeburg line admits the same figure for fir.

The Magdeburg and Wittenberg line place it at 16 years; whilst the Eastern of Prussia reduce it to 13 years; and the "Frederick William" (Electoral Hesse) to 10 years, when prepared under pressure, and, when by simple immersion in the boiling bath (Kochen), to only five years.

The Aix Dusseldorf and Ruhrort line, and the Rhenish Railway consider sulphate of copper of little efficacy, whatever be the mode of applying it, and have given it up; in Bavaria on the contrary they accord it, as well as the Boucherie process up to the present time but little used in Germany, the preference over others. The opinion of German engineers is on the whole very little in favour of this antiseptic, which is the most in vogue in France at the present time, because it has there proved its worth; if this is not so in Germany, it is with the mode of applying it that the fault must necessarily be found.

165. *Chloride of zinc.* — The proportion of replaced sleepers, which had been prepared with chloride of zinc by the process of exhaustion and compression, has been,

Oak, at the end of 16 years, 8.66 per cent on the older railways in Hanover; at the end of 13 years, 2.33 on the Bremen to Wunstorf line; at the end of 10 years, 1.60 per cent on the more recent Hanoverian lines; and 0.85 on the Brunswick line.

Fir, at the end of 8 years, 0.60 per cent on the Hanoverian Railways, and 0.33 only on the Brunswick lines.

Beech, at the end of 7 years, 29.69 per cent on the line from Cologne to Min-

den; a very unfavourable rate, when compared with the results obtained in Hanover.

At the end of 8 years, 5.50 per cent on the Brunswick Railways.

At the end of 10 years, 4.9 per cent on the Hanoverian lines.

Pine, at the end of 7 years, 25.25 per cent on the Baden line, and 41.50 on the Northern of Austria Railway "Emperor Ferdinand."

Although the experience of Hanoverian engineers tends to establish the fact, that the heart itself of oak is penetrated by chloride of zinc, not only in simple experiments, which are apart from the question, but under the ordinary conditions in practice, and although it has been ascertained that sulphate of copper also has superficially penetrated the heart-wood, yet it does not appear, that there is any reason to submit squared oak to a preparation, by so complicated a process as the exhaustive and compressive one.

Tar oil, which penetrates hard wood much more easily than any solution of salts, is certainly the only thing which might in this case be used with advantage. The prolongation for only a few years longer of wood, which in its natural state already lasts a dozen years, represents but a very small actual value, and could justify but a very slight expense of preparation, and consequently a very simple process, such as mere immersion.

166. The preparation is generally in favour with the German lines; some however, that of the lower Silesia for example, have systematically renounced it, and necessarily with it the use of those kinds of wood which cannot dispense with it, except in particular circumstances. Oak sleepers only are used upon this line, and not till they have been thoroughly seasoned and dried in the open air: the same is done on the Wurtemberg lines, where oak it is true is abundant, though fir and pine also grow there; the preference given to the first is however justified by experience (136).

The Dresden meeting (*), though considering, that it is impossible to deduce any very clear consequences from such contradictory results obtained on the German Railways, thought that the following might be admitted, as the approximative duration of the different kinds of wood; when in their natural state, and when well prepared.

(*) "Referate über die Beantwortungen" etc., in quarto. Janecke Bros, Hanover, 1865.

	MEAN DURATION.	
	Unprepared.	Prepared.
Oak.	14 to 16 years.	20 to 25 years.
Fir.	7 to 8 —	12 to 14 —
Pine.	4 to 5 —	9 to 10 —
Beech.	$2\frac{1}{2}$ to 3 —	9 to 10 —
Larch	9 to 10 —	» »

The Belgian government has some doubts as to the efficacy of the various preparative processes, which are shown by a condition inserted in the new concessions (20[th] February 1866.) granted to railways; in article 11, it states.

" The sleepers shall be of *oak*. — Nevertheless the Department of Public Works " reserves to itself the right to authorize the use of other kinds of timber prepared " with creosote, or by any other method, which shall have been previously agreed " upon ; in all cases the use of oak shall be compulsory at the ends of the rails, and " in curves of less than 50 chains radius, when the rails are not fixed on the sup- " ports by means of chairs. "

These clauses are but little in harmony with the liberal spirit, which usually animates the Belgian government in its relations with general industry.

Whatever opinion it may hold as to the efficacy of the different modes of preparation of sleepers, and of the relative value of rails with, or without, chairs, it is quite evident, that the public security can be protected in all cases. The question is essentially one of economy; by interfering in details of this nature, face to face with companies with a responsible management, the government appears to depart from its duties; it decides questions, which demand at least a fuller examination, and moreover by its decision exposes itself to the chance of throwing a check in the way of progress.

167. On the great systems of railway, such as those which divide the French territory, the kinds of wood in use naturally vary according to the different districts traversed. It is oak however which prevails, always squared and unprepared, unless it be on the Orleans railway; beech comes next, then fir, pine, and hornbeam, these are always prepared.

All sleepers of whatever kind of wood, unless they are to be prepared by the Boucherie process, should be stored sufficiently long in advance in the depots in order to dry. Any tendency to split may be counteracted by

tarring their ends; and if splits have taken place, they may be checked by applying S hooks, or better still bolts and nuts.

§ IV — Dressing of the sleepers.

168. The finishing of sleepers is a very simple operation, but the careful execution of it affects in a great degree the regularity of the motion of trains, and the security of working of the line.

This consists in, 1st the manner of making the notches, or seats for the rails, plates, chairs, or fish-plate-chairs; 2nd the boring of preliminary holes; 3rd the laying of the chairs.

For lines with chairs, having the unsupported fish-plate-joint, the three operations (sabotage) are performed at the yard itself; the sleeper when conveyed away to be laid has its two chairs already fixed to it. On chair-lines using fish-plate-chairs at the joints, the holes in the joint sleepers are bored on the spot itself.

With the inverted T rail the holes are pierced at the yard, except in the case mentioned farther on (169); but the spikes or screws are not put in until after the sleepers are laid (175).

1st *Nature of the seats.* — With chairs it is by these, that the inclination is given to the rail; the notches are therefore horizontal, or more strictly speaking in the same plane, unless it is for the joint sleepers, when fish-plate-chairs are used; in this case the notches should be inclined towards the inside of the line.

With the inverted T rail all the sleepers have the notches inclined, except sometimes those which receive the bed plates especially at the joint; as these plates are able themselves to give the necessary inclination to the rail, by their thickness on the inside being diminished.

The notches are made by hand, or by machine: the hand-made ones are still he most common, the workman having a template to guide him; for a chair line it is formed of two pieces of rail, 10″ long, joined together by a solid T crosspiece, thus representing a short length of line, and having exactly the gauge and the inclination required (Pl. VII, fig. 7).

For joint sleepers to carry a fish-plate-chair, flat wrought iron plates are substituted for the short pieces of rail.

With the Vignoles rail the crosspiece carries, either simply two plates, or two cast iron shoes with four vertical shaft-holes in each, *c, c, c, c*, corresponding exactly with the spikes or screws (Pl. VII, fig. 4 and 5); when there is a joint plate, the notch, larger than at the intermediate sleepers, is made by means of a special template.

In all these cases, as the largest and most regular surface of the sleeper should form its bearing or base upon the ballast, it is upon the opposite

side that the notches are made : the template is placed therefore upon this latter face, after having had, if it is a chair-line, two chairs very carefully keyed upon the rail ends. The sides, parallel to the rail, of the chair, plate, or shoe serve to indicate the limits of the notch, which is done by two saw marks, and which then is cut out with an adze; this is then verified by placing the template upon it, which should fit exactly into the two notches at the same time. The sides formed by the sawcuts should be preserved intact, especially on the outside; as they help to resist the thrust of the wheel-flanges, and thus assist the fastenings.

The depth of the notches depends on the shape of the sleepers, it should be at least $\frac{3}{8}''$, and sufficiently long with the inverted ⊤ rail for the bearing surface of the rail to be at least $5\frac{1}{2}''$ long; on the Paris and Mediterranean line 8″ is the minimum length of bearing for joint sleepers, the surface in contact with the rail must be moreover perfectly sound and free from soft wood. With semicircular sleepers of small size, $5\frac{1}{2}''$ length of bearing could only be obtained by reducing the depth of the wood under the notch to about 4″; in this case we must diminish the former dimension, so as to allow a depth of at least $4\frac{3}{4}''$ under the notch, as this is more important than that of the length of bearing surface.

Machine made seats or notches. — The employment of machinery in this case naturally recommends itself; not only is it more expeditious, but it also guarantees that minute exactness, which hand work cannot effect but with the greatest care : it is therefore astonishing, that the use of machinery is not more general for this purpose.

It would be difficult to class in order of merit those machines which are in use, and unnecessary to describe them all. That of Mr Denis is applied in Bavaria and on the Eastern of France line, that of Mr Castor on the Northern of France, and that which Mr Klauss has set up in the workshops of Göttingen, work successfully : the last we will take as an example, and describe it (Pl. VII, figs. 1, 2 and 3).

Motion is obtained by means of the shaft I from a steam engine (in the present case, it is the engine used in the exhaustive and compressive process of preparing the sleepers), and by it transmitted to another shaft A which carries the two circular planes *r*, *r*; this shaft is carried upon three bearings in order to ensure its rigidity, these bearings are able to move vertically in the hollow of the standards *p*, *p*, *p* (figs. 1 and 3). One of the planes, *r*, is keyed tightly on to the shaft A; the other is free to move longitudinally, and can regulate the excess in the width between the rails in curves, which varies with the radius.

The sleeper T is placed and wedged on the table *t*, *t*, and is brought beneath the planes. The vertical movement of the planes, which should be fastened at a

variable height on account of the unequal depth of the sleepers, is regulated by means of a screw, v, and of a conical toothed-wheel applied to each of the bearings, and worked by the levers R, R. The shaft makes from 1,000 to 1,200 revolutions per minute, and in less than thirty seconds the notches are made. The machine then pierces the holes, as will be seen farther on.

169. *Making the holes : 1st by hand.* — *a. Chair-line.* — In the preparation of sleepers for chairs the holes are pierced immediately after making the notches, by inserting the auger, perpendicularly to the surface of the notch, into the holes in the chairs, which are always keyed on to the template (fig. 7). The workman begins with the holes on the inside of the line, which he pierces to a depth of at least $4\frac{3}{4}''$; he then puts the screws in, but only partially; and having done the same with the outside ones, he gradually tightens them up, passing over from one side of the rail to the other, to avoid at all displacing the chair; when this is done the keys are removed, and the template set free.

The holes of the screws, or the spikes, for fish-plate-chairs are only bored on the spot, while the latter are being fixed, and after the gauge has been tested. On the Western of France Railway these holes are also $4\frac{3}{4}''$ deep; the spikes being only fully driven home, when the bolts of the fish-plate-chairs are finally tightened up. A gauge-template (Pl. VII, fig. 8) should be placed on the rails near the joint, whilst the spikes are being driven, to avoid the least deviation, which might alter the width of the line.

b. Vignoles Rail. — The auger is often, on the Northern and the Eastern of France Railways for example, inserted in the holes in the template; it is by this means guided in direction, but not in an absolute manner, on account of a certain amount of play. The same template (fig. 4 and 5), if there is no joint-plate, may serve, both for the joint and the intermediate sleepers; only that for the latter but two holes, taken diagonally, are used. The holes are pierced right through, both for screws and for spikes (170). The diameter of the augur is $\frac{9}{16}''$ on the Northern of France, for screws of $\frac{3}{4}''$ in the body; and on the Lyons line $\frac{5}{8}''$, for spikes the side of which measures $\frac{3}{4}''$; on the Western of France, the augur is of the same diameter as the body in the screw, viz., $\frac{9}{16}''$; in this case the screw only sinks its threads into the wood, and does not act with its body against extraction. The same augur is used for pegs of $\frac{3}{4}''$ diameter.

In the template of the Northern of France the distance, at right angles to the line, between the centre of the holes is $5''$; the distance therefore between the opposite edges of the adjoining screws is $5'' - \frac{3}{4}'' = 4\frac{1}{4}''$; as the foot of the

rail is $4\frac{1}{8}''$ broad, there remains $\frac{1}{16}''$ on each side between the rail and the screw for play, and to cover any accidental excess in dimension. On a part of the Lyons line, where holes are not pierced in the template, the dimension taken is the position of the centre of the hole relatively to the edge of the rail; this distance is $\frac{5}{8}''$, which, with a $\frac{3}{4}''$ spike, presupposes as its normal state, instead of play being allowed, a slight widening out, $\frac{1}{32}''$ in each spike, by the foot of the rail.

The width of the holes apart is necessarily less for those sleepers, to which the rail is attached by means of small notches, cut in the foot of the rail. To avoid confusion in laying the line these sleepers are only bored on the spot, even though the others may be previously prepared.

For joint sleepers the distance between the holes, both outside and in, should be such, that they are not impeded, whilst being put in place, by the bolts of the fish-plates; also if there are stop wedges (107), the screws must not interfere with their being put in position. All these conditions are fulfilled by a distance from centre to centre of $4''$, between the outside holes; and of $2\frac{3}{4}''$, between the inside ones.

2nd. *Boring the holes by Machinery.* — This is done by the same machine, which makes the notches.

In the apparatus of Mr Klauss (Pl. VII, figs. 1 to 3) the augers θ, θ, θ, either eight, or four in number, according as joint or intermediate sleepers are to be operated upon, receive their rotatory movement from the motive shaft I above the planes; and which is transmitted by the bands *c, c, c, c*, acting upon the rollers ρ, ρ, ρ, ρ, and round the pulleys $\varpi, \varpi, \varpi, \varpi$. The guiding rollers, ρ, are at the same time tension ones, regulated by means of the weight P, suspended to the lever L, which carries the rollers. The augers are advanced into position, and also withdrawn by hand, by means of the counter weighted levers λ, λ (fig. 2). The half of each group of augers, viz., one or two, rest on their supports by means of slide blocks, which can receive two horizontal movements at right angles to each other, by means of small winches V, V (fig. 1); thus allowing of the distance between the holes being regulated at will.

170. This preparation should be very carefully verified; the exactness of the template itself ought to be tested each day by means of a gauge, fig. 9 (Pl. VII) for the inverted T rail, and fig. 10 for a chair line; the gauge (fig. 9) may also be used after the line is laid to verify the width, and the inclination of the rails. For the chair line each sleeper is submitted, on the Western of France, to a special examination by means of the gauge J (figs. 11 and 12); if the projecting pieces *m, m'*, shaped on the inside to the hollow of

the chair, cannot enter it, the sleeper is refused, as the notches are then too wide apart; if, on the contrary, it fits in too easily, the gauge is reversed (fig. 12), and the projections n, n', inserted into the hollow of the chair, which are $\frac{1}{8}''$ less apart, than the others m, m'; if in this position the gauge drops in too easily, it shows that the notches are not sufficiently wide apart, and the sleeper is likewise refused.

171. It is important to keep the wood quite separate from the iron, their contact causing a very rapid destruction of the woody fibre, especially in beech. The sleepers on the Sceaux line offer a very striking instance of this change; it was attributed in this case to the sulphate of iron, caused by the reaction of the metal of the spikes and of the sulphate of copper, with which the sleepers had been injected. But this alteration is produced also, though perhaps in a lesser degree, in unprepared sleepers, such as oak.

Oxide of iron appears therefore to be a very powerful agent in the decomposition of wood, so that it is indispensable to protect the pegs, spikes, and screws against oxidation; which is obtained only by galvanizing them. This is done on the Northern of France Railway with all the sleepers, whether prepared or not.

The sides of the holes are moreover, as are the seats or notches, coated with tar, applied warm on the dry wood. Often the sleepers are not pierced right through in consequence of this coating of tar, and likewise to increase the resistance of the spikes to extraction; experience however appears to have condemned this practice, for, if the tar comes out, water takes its place, the hole cannot be kept dry, and decay makes very rapid advances; also the additional depth of wood through which the spike forces itself is unnecessary, since the resistance to extraction, obtained with a hole pierced right through, more than suffices.

On the Paris and Mediterranean line only sleepers prepared with sulphate of copper are tarred; vegetable tar alone should be used, gas tar is strictly excluded. On the Northern of France tarring is also used, the same efficacy is not however attributed to it as elsewhere; the holes, pierced right through, are plugged, and filled with tar.

If the sleepers are charred, the holes should be the subject of a special operation; Mr de Lapparent advises carbonizing their sides, previously coated with tar, by means of an iron bar, made red hot in a small portable furnace. Although the hole is enlarged by it, the peg, or the spike, is kept in contact with wood altered in character, by local distillation at least.

§ V. — **On the utilization of old sleepers.**

172. Railway companies always endeavour to get as much work as possible out of the sleepers before finally throwing them on one side; sometimes their duration is extended by being adzed completely afresh, if their dimensions, and the condition they are in, admit of it; and sometimes those sleepers are placed in sidings, which are unfit for the main line: however they all ought to be redressed. The old holes should be first plugged with sound oak pegs, well tarred; while making the fresh notches or seats, all decayed wood must be entirely removed, and care must be taken in making the new holes to avoid the old ones.

On chair-rail lines, the old sleepers are sometimes put to a use, which is every day becoming rarer; that of making the sound portion of them into wedges. However when they are finally taken up their value is almost null, they are sold at a low price for firewood, which is found to be so poor, that the sale scarcely covers the expense of removal.

There is however another use, happily very rare, for cast aside sleepers: viz., in those parts, which are subject to downfalls of snow. Thus on the Northern of Spain Railway in 1865, in the pass of the Guadarrama Range, stockades were formed with sleepers withdrawn from use on the line, and which proved very effective. They were used in the same way on the line from Laybach to Trieste over the Karst mountains, but this had to be given up; as, owing to the extreme scarcity of wood in this arid country, the inhabitants destroyed these barriers to obtain this very inferior fuel, which elsewhere would offer but little temptation.

173. *Composite sleepers of Mr Huber.*— The destructive wear, which causes the removal of sleepers, does not affect them equally throughout their entire length; the middle part is often nearly intact over a length of about 3 feet, or more, even when the chair seats, and the ends are split and rotten.

Mr Huber, inspector on the Northern of France Railway, proposed to form composite sleepers of two ends, made out of the sound parts of rejected sleepers, joined together by two iron bands, on top and bottom, and bolted together with screws (Pl. VII, fig. 23). He estimates the net cost of such a sleeper at 3s of which the value of the wood would be only 4d.

Experience must decide as to the practical value of this project; there appears however in it another useful method of utilising the timber more completely, than is at present the case. Perhaps without altogether doing away with wood, and replacing it by iron supports, it might be well to try to reduce the cube of the former so as to retain merely those advantages, which are peculiar to it, while using it of a sufficiently large size, an indispensable condition to its durability.

CHAPTER VI.

BALLAST.

174. *Conditions which it should fulfil.* — Good ballast should comply with many conditions; water must percolate easily through it, in order to ensure the drainage of the line; its component parts should possess a certain amount of freedom to move, which can give flexibility to the line, and consequently a smoother movement to the trains. Its elements ought likewise to resist frost, water, the mechanical action of the carriages, and the wear of the maintenance; they must not have too much adherence between them, and yet there must be sufficient stability to be neither whirled up by the currents of wind, caused by the passing of the trains, nor by the movement and the vibrations of the sleepers; movements which the resistance of the ballast ought to maintain within very narrow limits, while at the same time leaving them somewhat free.

The ballast in fact performs a very leading part; for by transmitting the pressure to the natural ground on the level or in cuttings, and to the made ground in embankments, it distributes it over a greater surface, than that upon which it rests itself. Moreover it effects this distribution in some sort in proportion to the resistance of each element; loading more heavily those which have greater resistance, and less those that have a tendency to yield. Such is the property of resisting-thrust, which a mass of incoherent elements possesses, but the normal reactions of which produce a considerable amount of friction. It suffices here merely to state this property, and not to discuss it; adding only that the greater the pressure to be transmitted, the greater also must be the depth of ballast to demonstrate this property.

With a defective ballast it is difficult to keep the line in good order, even with a costly maintenance; the wear of the rails and of the sleepers is besides more rapid, not only on account of the imperfect state of the line, and from the more violent reactions of the trains consequent upon it, but also from the increased labour of maintenance: the oftener the permanent way must be handled, the sooner by this very fact do its elements become deteriorated.

Good ballast is all the more necessary, in proportion as the variations in the condition of the atmosphere are more frequent. When a thaw succeeds to a

prolonged frost, the sleepers, which have not for some time previously been able to be packed up, are often unsupported, they balance up and down, their pegs or spikes get loose; and these results are all the more serious, as the ballast is less permeable.

Gravel, or gravelly sand, having its grains of various sizes, fulfils better than any other material the whole of the above conditions; gravel dredged from a river may be considered as the type of a good ballast; that which is extracted from quarries has sometimes too much clay mixed with it, which renders it but little permeable. Railways which follow the valleys generally find gravel close at hand, particularly if they keep well down in them. It is not so on the high level grounds, gravel must then be replaced by broken stone, and in default of this, by artificial productions.

Most kinds of rock are suitable; provided they are neither acted upon by frost, nor are too soft, nor yet too hard, and consequently too difficult to break. Chalk is almost the only kind, which should always be rejected; it is too friable and dissolves with water. Granite with much felspar should also be excluded; it soon produces a clayey paste, which is a hindrance to the proper drainage of the line.

The broken stone should always pass through a ring $2\frac{1}{2}$ inches at most in diameter, and be clean from earthy particles and broken fragments; it is always however less convenient to pack up than is gravel. Sometimes sand is mixed with the broken stone; but it forms a bad mixture, as the sand merely fills up the interstices between the stone, and does no good; it even does harm under the sleepers, cementing together in some sort the stone, and forming with it a kind of compact concrete, wanting in flexibility.

It is however sometimes necessary to repair with sand a section of line originally ballasted with broken stone, or vice versâ; they should nevertheless each be kept as separate from the other as possible. Thus on railways with two lines the sand should be used on the one, and the stone on the other; on those lines having only a single way the sand might be used between the rails, and the stone employed on the outside (*).

The section from Naples to Capua of the Roman railway was originally ballasted with puzzolana only, which produced, like the fine sand of the Landes of Gascony, a dust as disagreeable to the passengers, as it was hurtful to the rolling stock; this has lately been covered over with a layer of broken stones, but the expedient will no doubt be insufficient, and the puzzolana will probably be done away with altogether.

(*) Paris and Mediterranean Railway, Instructions dated May 19th 1865.

175. Artificial ballast is produced from baked clay, and the refuse from certain works.

Baked clay, a species of coarse brick, which is afterwards broken up, is used in England and Holland; if too little burnt, it does not answer well.

The refuse used from works consists of, iron slag, zinc dross, and furnace cinders. The first makes a very good ballast, it is very permeable, and easily packed up; on the line from Mons to Hautmont, and from Erquelines to Charleroi, no other is used; it is obtained from the iron works and boiler furnaces so numerous in the district, which they pass through.

The line from Namur to Liége is almost entirely ballasted with dross, which comes from the zinc furnaces, and contains iron slag, and the refuse of the crucibles, etc.; Mr Bernard, considers this ballast is even preferable to iron slag. It is however more especially furnace refuse, that ought to be made use of for ballast; iron works are often obliged to purchase land at a great cost, on which to deposit their dross, and which soon forms immense mounds, especially in districts where the minerals are poor in quality.

By sifting the refuse through water (*) Mr Minary has succeeded in both greatly simplifying the operation of cleansing, and in reducing it at but small cost to a state in which it can be immediately used for ballast. The trials made by the Paris and Mediterranean Railway Company on this head are satisfactory.

The dross, whether in this form, or in the ordinary one, viz., after being broken up, an expensive operation it is true, may be made available at a considerable distance from the works; which ought by some inducement to make it worth the while for railways to relieve them from the accumulation of slag, with which they are encumbered.

The cube of the ballast varies; on a double line using chairs, it ranges from 4 to 6 yards cube, the former however is the most common; the corresponding depth of it being 2′ 0″, of which half is underneath the sleepers.

With the inverted T rail the cube is less, the depth of ballast above the sleepers being usually reduced to 1″ (see Pl. VII, fig. 25, the type section of the Northern of France Railway); and oftentimes there is none (32).

In Belgium, the new terms of concession for Railways prescribes, that the ballast shall have a minimum depth of 8″ below the sleepers; and 2″ to 4″ above, according to the method of fixing the rail on its supports.

176. *Provisional ballasting of a line.* — The top of the earthworks having

(*) See the description by Mr Resal, mining engineer, in the "*Annales des mines*," 6th series, vol. VIII, 1865, p. 115. Of a cleansing machine put up at Fraisans by Mr Minary.

been levelled off, the centre of the railway is pegged out, at intervals of 100 to 200 yards for straights, and every 50 yards for curves, the heads of the pegs being exactly level with the rails; longer ones are placed at the beginning of all the curves, and at changes in the gradient; afterwards while the rails are being laid their centre line is marked out with poles. This done, the sleepers are approximately distributed over the surface, beginning with the joint ones; the rails are then laid down, the width of the joints being regulated according to the temperature (122); the keys are next inserted, if the nature of the rail requires them, and merely moderately tightened; lastly the fish-plates are fixed by hand, with only two bolts however.

The object of this temporary laying of a line, which must afterwards be taken up again, is to make use of it not merely for the transport of the materials which serve to extend it, but also of the ballast upon which the provisionary line itself is laid. As the materials per lineal yard of a double line represent a considerable weight, 7 tons nearly for a chair line, the economical transport of such a mass is of evident importance. The difference between the level of the line laid upon the ground, and of the one somewhat raised, of which it is the extension, is made up by a small inclined plane; the waggons carrying the rails and sleepers from the depot, as well as the ballast trains can thus continue their journey on the provisional portion of the line.

However any circulation at all considerable upon this very imperfectly laid line, especially if an inverted ⊤ rail simply placed upon the sleepers is used, might cause much damage to its elements, and thus render the economy but illusory.

The instructions given on the Northern of France Railway for laying an inverted ⊤ line, recommend " that it shall be so arranged, as never to allow more than one train to pass over the ballast without its being lifted." Every ballast train as soon as it reaches a portion, where the rails are placed upon the ground, is stopped, when its whole length is upon them, and is discharged on the spot; immediately it is drawn back, the rails are raised and the ballast packed under the sleepers, which are elevated by means of long levers.

The ballast is laid in at least three layers; the two first are usually from 4″ to 6″ each in thickness; sometimes even, on the Northern of France for example, these are only from 2″ to 4″ thick; the last layer is regulated according to the type section of the line. It is only when the rails are at their definitive level, that the fish-plate bolts are screwed up tight.

The intermediate sleepers are then laid in position very exactly by means of a long graduated rule; and their screws are fixed, and tightened up with a key. The joint-screws are then fixed : it is best for this purpose to com-

mence by removing the fish-plates; a cross headed key may be employed for this purpose as much more expeditious than the forked one, which is used for the maintenance; this being done, the fish-plates aré replaced, and screwed up with their four bolts.

The gauge of the line, the spaces between the joints, and the amount of cant in the curves (200), are then verified. This last verification is simply done by means of a spirit level, and of the rule R (Pl. VII, fig. 6), which bears on each of its two horizontal faces six steps, corresponding to as many radii inscribed on its two sides.

The action of the first trains necessarily produces some derangement amongst the elements of the permanent way, independently of the serious and often persistent one caused by the settlement of the surface in embankments. It is desirable therefore to postpone the final ballasting, till these slight alterations have taken place, and have been remedied by being carefully packed up.

Of course where the line is to be double, it is only the first that is laid provisionally, as this will serve to transport the materials of the second, which is placed at once at the proper height; that is, upon a layer of ballast of 12″ in thickness, in which case the waggons are unloaded sideways.

CHAPTER VII.

STONE BLOCKS AS SLEEPERS.

177. We must go back to the commencement of railways to find the first form in which the permanent way was laid without the aid of wood.

In England, in Germany, and in France, at first the rails were laid on stone blocks; it is now nearly 40 years since the line from Liverpool to Manchester was laid down in this manner.

As long as the trains went but slowly, timidly so to speak, these blocks were sufficient; but their inconveniences, and especially the most serious of them all, the instability arising from want of connexion in the permanent way, became apparent as soon as railways, emancipated in some measure, and being conscious of their power and their mission, sought to realize one of the essential conditions of their nature, viz., speed. Although changes back again may be somewhat difficult to be understood in the order of purely material facts, they often occur in the history of railways; but if there is one which might have been unlooked for, it is returning again to the system of stone blocks, and which has been done for some time.

It is true, that the engineers, who have been lately converted to the use of stone blocks, are but few in number. Bavaria uses them at present on a large scale, but she had never abandoned them; her example appears only so far to have been followed by the Werra Railway and by the Hanoverian line, which however by no means consider the question as solved in favour of blocks; they use them only as an experiment to allow the engineers to judge for themselves.

It is well however to remark, that if the use of stone blocks is again in favour in Bavaria, it is especially in consequence of the substitution of the Vignoles rail for the chair-rail, with which the fastenings were often loosened, and the blocks frequently fractured.

The first trial of the Vignoles rail on stone blocks goes back to 1850 (100 rails in a curve of $14\frac{1}{2}$ chains radius near to Hof); fish-plates and bed-plates were used at the joints, and, a point which should be noted, the blocks were of granite. At first in 1841 Keuper sandstone was used, but it was found too soft.

When about 1860 the rails and sleepers on the Northern and Southern, and

on the Western railways in the same country, had to be partially replaced, the old blocks belonging to the double-headed rail were again made use of for the new inverted ┬ rail; and new blocks, either of granite or sandstone, were substituted for the sleepers.

The Bavarian engineers state, that these sections have always stood well, that this method of laying requires very little maintenance, and that it is in no respect inferior to others; so that the advantages it evidently possesses, viz., durability, and greater mass in the supports, ought to decide the question in its favour.

It must be acknowledged, that Bavaria is especially suited for making comparisons of this kind, since every form of permanent way is represented there. In consequence of this comparison the administration of the Government Railway have adopted the inverted ┬ rail on stone blocks, as the normal type of permanent way.

There are however certain reservations made; thus, while stating the principle, that a permanent way on blocks in general is very firm, does not sink, yet preserves well the inclination and the gauge of both lines of rails, notwithstanding the absence of any connexion between them, the Bavarian engineers do not go the length of pretending, that this would be equally the case on new embankments and in curves. They readily allow, on the one hand, that sleepers are preferable to blocks, where the surface of an embankment is not sufficiently consolidated, or where the drainage is imperfect; and on the other, that the connecting together of the two lines of rails, and consequently the use of sleepers, at least partially so, is necessary in curves, when the radius is less than a certain limit.

It is needless to add, that the employment of blocks is subordinate to another condition, that of finding a stone, which is easily and cheaply procured, and yet which is hard, tough, and sound.

The use of stone blocks is therefore limited in Bavaria to those sections, which have been made some time, where the embankments have thoroughly settled down, the ballast is of good quality, either gravel or broken stones, and where the surface of the line is well drained. In curves at the joints the blocks are replaced by a sleeper, and sometimes in the middle is this also done. The blocks are from 12″ to 14″ thick, and are about 2 feet square on the bottom, the upper and lower faces ought to be dressed, and be parallel to each other : the block, solidly wedged up, is placed diagonally in order to give the rail a greater length of bearing; the joint blocks having four holes in them, the intermediate ones two, $1\frac{1}{2}''$ in diameter, which receive wood packings into which iron pegs are made fast.

The fastening is the delicate point, as the stones frequently burst during the first winter : however no heed need be taken of this, unless several blocks in succession are broken. The packings, of well seasoned oak, are steeped in tar oil; the holes, being well cleaned and dried, are half filled with hot tar; and again, after they are driven in, more tar is poured over the surface of the block.

When blocks are substituted for sleepers, while temporarily retaining the chairs, the holes are necessarily wider apart than for the inverted ⊤ rail. To avoid piercing new holes when this rail comes to be substituted, which would be too close to the first, they are bored parallel to the sides of the block, which is placed square with the axis of the line : the same holes afterwards serve for the inverted ⊤ rail, as the diagonal position in which the block will then be placed, brings them closer to the rail.

Experience has proved, that the use of any intermediate compressive substance, such as felt, wood packing, etc., which were in use a long time, may be dispensed with; they are no longer applied but to old blocks of soft sandstone; occasionally also in winter they are added, when inequalities are formed by frost, which cannot be remedied by packing up as long as it lasts.

In Bavaria, where the blocks cost at the outside but 2ˢ, economy is in their favour, as compared with oak sleepers, but against them if with beech, or fir ones. The engineers there however maintain, that the pegs have not sufficient resistance, when fixed in the last mentioned woods, to prevent the gauge widening out in curves; this assertion however is difficult to reconcile with the experience acquired on a great many other lines, and with that of the Bavarian lines themselves, where the insufficiency of stone blocks has been amply demonstrated, as well as the necessity of the partial employment of sleepers in curves. It is granted, on the other hand, that the first laying is a little dearer with stone blocks, and the maintenance is also somewhat more expensive during the first year : but that before long, the parts become consolidated, and the advantage then lies the other way.

However this may be, the state Railways in Bavaria contain at present more than 500,000 stone blocks, and they are taking the place of sleepers still more every day.

Though admitting, that the measure adopted in Bavaria is perfectly justifiable, it can only be recognized as having but a local value. Apart from the conditions of the relative price of stone blocks, and of wood sleepers, it must not be forgotten, that the trains in Bavaria travel at a prudently slow speed, and the extent of the accommodation is at the outside, but one through train per day for the whole journey between Paris and Vienna.

If however the speed, of from 25 to 30 miles per hour, were changed to from 45 to 50 miles, or more, the conditions to be fulfilled by the permanent way would be entirely altered. It is moreover to be noted, that the example of the state Railways in Bavaria has hitherto been followed by none of the Railway Companies. Even the line of the Palatinate, which made use of blocks between Ludwigshafen and Bexbach, and afterwards abandoned them, does not seem disposed to return to them again.

178. In relaying the permanent way of the Baden line, between Carlsruhe and Dürlach, a peculiar method was used with the inverted ⊤ rail, suggested by the desire to utilize materials, which could not otherwise have been turned to account (Pl. VI, figs. 41 and 42).

The longitudinal sleepers when in cuttings rested, as has been seen (116), on blocks of sandstone 5 feet apart, and on the level on blocks and sleepers alternately. The method adopted consisted in the combination of the two together, longitudinals 22 inches long were let into the soundest blocks to a depth of 4 inches; these compound supports were placed 1′ 10″ from one another. This method of laying was costly, on account of the cutting out of the blocks; and besides the experience derived from it has not been satisfactory.

179. Several attempts have been made to employ stone in the form of sleepers; thus in 1847 several sleepers of granite were placed near Görlitz, in Prussia; but, as might have been expected, they broke in the middle, and the tendency also to turn over was much more decided than with square blocks. In this form deflexion takes place more or less; and this consideration alone is sufficient to prevent the employment of stone, even in the very rare cases where blocks of the necessary dimensions can be found cheap, and ready to hand.

CHAPTER VIII.

SYSTEMS OF PERMANENT WAY ENTIRELY METALLIC.

The different forms of entirely metallic permanent way, which have been tried up to the present time, may be divided into four classes.

1st. With ordinary rails, either double-headed or inverted ⊤; the wood sleeper being replaced by cast iron supports, with wrought iron cross ties.

2nd. Especially applicable to the inverted ⊤ rail; the transverse supports are of wrought iron, and in their general form resemble wooden sleepers.

3rd. Excluding the use of the chair rail; the metallic supports are placed longitudinally; it is, in fact, only with a less number of inconveniences, a system of longitudinal sleepers (110, etc.).

4th. The rail itself is considerably modified, and rests immediately upon the ballast; it is either simple, or formed in several pieces, in which case it resembles the preceding type.

§ I. — First Class. — Cast iron supports.

180. *Greaves' pot-sleepers*. The oldest, and up to the present the most widely used arrangement, although its success has been somewhat chequered, is that of Mr Greaves (Pl. IX, fig. 29). The sleeper is superseded by two spherical bell-shaped vessels C, C, connected by a cross tie *t*, intended to preserve both the gauge, and the inclination of the rails.

Mr Greaves having designed his system in connection with double-headed rails, the top carries two jaws *a*, *a*, stiffened by two ribs, *n*, *n*, which form the mouth of the chair. The support is in reality, a chair with a much enlarged base, bell-shaped and provided with openings, which greatly facilitate packing inside. On account of its complicated shape this must, like ordinary chairs, and even still more so, be necessarily made of cast iron. The cross tie, *t*, which ought to be rigid to prevent the pots from turning over, is a rectangular wrought iron bar placed flatwise, passing through the pair of supports, fixed to each by two keys, and thus precisely determining their position.

This system has been, and is still, of undeniable service on several lines, where the use of wood was out of the question. Such was the case on the Isthmus of Suez Railway. The resident engineer M^r H. Rouse, stated in 1862, that an experience of ten years fully justified the preference given in 1851 by M^r Robert Stephenson to M^r Greaves' pot sleepers; and that this kind of permanent way was more suitable, than any other to the climate, and to the nature of the ballast, which consists of sand and alluvial deposit of the Nile.

The value of this testimony, confirmed in 1865 by the reports of the divisional Engineers, cannot be denied; but persons, who have travelled over the Egyptian Railway declare the permanent way to be in very bad order; it remains to be learned, how much of the fault lies respectively with the supports, the ballast, and the maintenance.

In India opinions are divided; whilst the engineer of the East Indian Railway rejects Greaves' supports, those of the Madras, and of the Calcutta lines, as well as those of the Punjaub, declare themselves very well satisfied with them. The application made in the Punjaub extends over nearly 70 miles between Montgomery and Mooltan. "Never" says the engineer in charge of the rolling stock, in a report made in 1864 "have I travelled over a better road; the speed is moderate, it is about 25 miles per hour."

It is allowed also that these pot sleepers do good service in Brazil; but it is probable that people there were very easily satisfied, in order to escape at any price from being obliged to use the wood of the country, which would have hardly lasted more than three years at the most: the speed of the trains is besides very slow.

The pot sleepers are likewise adopted on the lines of the Argentine Republic; where they superseded, as being more economical, the Barlow rail, which after being altogether abandoned in Europe received in this distant region its latest, and probably also its last application (193).

Some engineers object to these supports, in common with metallic ones in general, owing to the very marked influence they exercise on the depreciation of the rails, and of the rolling stock; the experience gained upon the Indian Railways appears however to have proved this objection to be without foundation.

The maintenance of the permanent way proper is burdensome, and expensive; as this system requires the ballast to be small grained, and as the fine sand, often obliged to be used in tropical countries subject to deluging rains, has the capital objection, that unless protected by side walls, which are costly but effective, the entire ballast would be swept away.

These bell-shaped sleepers, apart from their fragility, as well as from the inconvenience of excluding any ballast composed of broken stones, have one capital objection, which they possess to a greater extent than wooden sleepers even; viz., that the surface of the ballast over which they distribute the load is altogether insufficient to it, an objection which cannot be diminished without increasing to exaggeration their base, and consequently their thickness and their price. A similar system has been recently applied on the first section of the Central of Venezuela Railway, from Puerto Cabello to San Felipo; the cast iron supports, tied together with wrought iron rods, are 26″ long by 20″ wide; their upper face is convex and carries a couple of cheeks, between which the single-headed rail, fish-plated, is keyed up with cast iron wedges.

181. In France on several lines, amongst others the Eastern and the Western, a proposed arrangement of Mr Henry's was tried a few years ago under the name of chair-plates, which had some resemblance to those just described; the support consisted likewise of a chair much widened out, and with a flat base. This trial was not successful; the permanent way was deficient in stability, the necessary thrust of the ballast being completely wanting; the cross ties, simple gauge rods, did not maintain the inclination of the rails; in fact merely a few waggons running off the line sufficed to break everything, both chair-plates and tie rods.

182. The exclusive use of wood in England, the land of iron, proves that the former offers great advantages over the metal; or at least that the use of the latter under a suitable form has not yet been arrived at.

The question of the employment of iron could not be neglected on this side of the Channel; it has long been studied here, but as the success thereof was doubtful, the problem has been almost abandoned, and English Engineers take scarcely any part in the experiments upon this subject, which are being made on the Continent. They generally are agreed in considering the employment of wood as necessary; and, thanks to the efficiency of tar oil, usually called creosote (143), and of which the supply is sufficient for all requirements, they appear very well satisfied to leave matters as they are. Moreover it is undeniable, that the spirit of inquiry and of economical investigation is much less active among Railway Companies in England, than amongst those of France and Germany.

As an example of the various arrangements tried in England it is sufficient to mention the cast iron self-supporting chair of Mr Peter Barlow (Pl. VIII, figs. 30,

to 32). This support partakes at once of the nature of the fish-plate-chair, of Greaves' pot-sleeper, and of the chair-plate of Mr Henry.

Each support is formed of two jaws bolted together and griping the rail; two kinds are made, one for the intermediate bearers, and the others for the joints; the latter (figs. 31 and 32) is longer, carries three chairs instead of two, and its two jaws are connected by four bolts in place of two; it receives also the cross tie *t*, which fixes both the gauge and the inclination, keyed to each side of the support. The centre chair or jaws, *m*, in the joint support may also be advantageously replaced by ordinary fish-plates.

In the arrangement shown in figs. 33 to 35, and which is likewise due to Mr Peter Barlow, the support is in one single piece, and the rail is then fixed tight by means of two wooden wedges *c*, *c*; ordinary fish-plates are used at the joints (figs 34 and 35). The cross tie, *t*, bolted on to a projection in the support is much closer to the top of the rail, and therefore more effectually prevents it turning over; it is besides very rigid.

Both these forms have been tried on the Midland Railway, the Eastern Counties lines, in Ireland, etc., and, if the result thereof has not been decidedly bad, it has not been sufficiently favourable to procure its application on a larger scale.

183. A system of cast iron supports, designed by Mr de Bergue, and tried for some years with success on the South Wales Railway, has been recently applied on a length of about three quarters of a mile on the London, Chatham and Dover line, near the Victoria Bridge. This method had previously been tried in Spain, though on a much more extended scale. First used in 1853 on the line from Almanza to Valencia, and at Tarragona, it has since there received a considerable extension, 40 miles in 1863, and 140 since that time. This however, at least in the absence of any proof to the contrary, is only a relative success; in Spain wood wears very badly, as much on account of the deteriorating influence of the climate as through the kinds in use, and also of its being almost always imperfectly prepared. It is quite possible, that under these conditions cast iron supports may be preferable to wood; they do not however appear able to bear comparison with a properly constructed wrought iron permanent way.

A system proposed by Mr Adam has been tried in India on the Bombay and Baroda line, which consists essentially of angle irons bolted on to the rails; it is however wanting in solidity, the pressure being distributed over too small a surface of ballast; no further trial of it has since taken place.

§ II. — Second Class. — Wrought iron sleepers.

184. They ought to fulfil the following conditions.

Their horizontal projection, and their vertical ones, parallel and at right angles to their longitudinal axis, ought to distribute over a sufficiently large surface of ballast the vertical load and the horizontal pressures, which tend to displace the supports in a direction, either parallel or perpendicular to the rails : they ought also to be substantial enough to afford a very firm connexion for the rails, without however being too heavy, and consequently too dear.

This condition of comparative lightness appears at the first blush to be one of the greatest objections against the use of wrought iron, at least on lines run over at a high speed. It is possible with a slight thickness of metal to obtain a bulk and a momentum of inertia apparently sufficient, and at the same time afford a solid hold for the rail; the wood sleeper however does not act only by its dimensions, which distribute the pressure over the surrounding ballast, though still hardly sufficiently so, but it also acts very effectively by its own bulk, which directly receives the almost inevitable shocks, and diminishes their effect. The metallic sleeper, being necessarily much lighter, appears in this respect to present an inferiority, the value of which experience alone can determine (189).

An arrangement, as made at the manufactory of Couillet in Belgium, is shown in Pl. IX, fig. 30. The support is a double ⊤ iron placed flat on the ground; this form, besides being a very generally made one, is very well adapted to fulfil the conditions just specified, with the exception however of that which relates to the end thrust, and which is of special importance in curves; this could however be provided for by means of an end piece projecting downward, which also would cost but little.

The rail is separated from the metal by a packing of oak *c*, *c*, which fills up the projection of the ⊤, and also gives the inclination to the rail; this addition is an almost unavoidable result of the form of the support, but the intermediate use of the wood between the iron appears neither necessary, nor advantageous.

In Bavaria, as we have seen (177), the rail is placed without hesitation directly upon stone blocks; and, provided there be no play, there should be no more fear in similarly laying the rail upon metal. It is especially in the arrangement adopted by the Couillet ironworks, that his wood packing appears to be defective; a wooden wedge with the grain upright would be too easily split, and with the fibres flatwise it is subject, as in the case of the

wooden keys for chairs, to all the influences, which cause the thickness of wood to vary.

The mode proposed by Mr Desbriere (Pl. IX, fig. 31) is preferable in some respects, the rail being transversely tightened up by the stop key *e*, and the wrought iron heads *t*, *t*, riveted to the sleepers, forming the fixed stops. This method nevertheless is liable like the foregoing, to allow some play, and consequently to an up and down movement, caused by the contraction of the wood. These Couillet sleepers weigh nearly 1cwt, and they cost 6s a piece; a trial has been made on a length of some hundreds of yards on a branch, having an incline of 1 in 100, and with curves of 15 chains radius, which connect two workshops; the engines, four wheels coupled, weigh 20 tons, with a load of 11 tons on one pair of wheels; the result appears to be good notwithstanding the difficult conditions of the nature of the line; but the speed is slow, which in matters of this kind is the chief stumbling block.

185. *Fraisans Sleepers.* Mr Zorès and the Franche-Comté Ironworks Company have endeavoured for several years to design a wrought iron sleeper as a substitute for wood, while using only those forms of iron in which it is ordinarily manufactured. The width in these sleepers is increased to 9″; the height similarly augmented, increases their moment of inertia and their thrust.

The wood packing is done away with, and the rail is supported on a bed plate P (Pl. XI, figs. 4 to 7), of which the principal function is to give the inclination to the rail, and to secure the solidity of the fastenings; which the slight thickness of the bearing iron, and the smallness of the surface of support would probably not guarantee sufficiently.

The fastening down of the rail, which is always the difficult point, appears well devised; the bed plate P, is fixed beforehand to the support by three rivets. The edge of the foot of the rail is easily inserted beneath the very broad and hooked head of the intermediate rivet *r*, and the connexion is completed on the inside:

1st. By a stop block *p*, the shoulders of which ensure the exact application of the foot of the rail upon the bed plate.

2dly. By a wedge *c*, which when driven home tightens up and connects the whole.

At the joint of the rail, the bed plate, P, necessarily longer, and at the same time also too wide to obtain sufficient bearing surface upon the narrow top of the sleeper, is supported by two cast-iron brackets T, T, (figs. 1, 2, 3); it is fixed to the sleeper by six rivets; two short ones *r*′, *r*′, fasten the top of the

sleeper, and four long ones ρ, ρ, ρ, ρ, its lower edges *l*, *l*. The two large hook-headed rivets *r*, *r*, which press the foot of both rails, as well as the blocks and wedges, necessarily beyond the reach of the bed plate P on the narrow top of the sleeper, cannot grip the latter in the same way, as in the intermediate sleepers. This joint sleeper is in fact heavy and complicated, it is however being modified.

A trial of this system made first on the branch, which connects the Fraisans ironworks with the line from Dijon to Besançon, has led to its application on the Lons-le-Saulnier line; and so far all goes well. A trial, which commenced in the middle of 1865, is being made under more conclusive conditions, on account of the increased rate of speed, on the main line from Paris to Mulhousen; up to the present it has answered very well.

In this experiment two different forms of intermediate sleepers (Pl. XI, figs. 5 and 7), as well as the joint sleepers (figs. 1 to 3) are being tested.

The Paris and Mediterranean Railway Company, are about to follow this example, and to try it upon a length of about 5 miles on the main line near to Paris.

The original arrangement has however at the hands of this company received some improvements in its details; they are shown in Pl. X, figs. 1 to 26.

The bed plate P, fixed ordinarily by two rivets, but by three at the joint, has on its outside edge a lip *e*, under which the edge of the foot of the rail is inserted: a stop block *p*, tightened up by a wedge *c*, grips between its two projecting shoulders the sleeper and the inside edge of the foot of the rail, and preserves the latter in close contact with the bed-plate; at the joint there are two fastenings placed on either side of the single rivet which is on the inside. When, owing to lengthened use and to the wear of the two surfaces, the wedge has sunk up to the head, it may again be made use of by inserting a key wedge, or packing (fig. 26), between it and the bed-plate.

The angle iron cross ties, *a*, *a*, (figs. 1, 2, 13, 14, 19), riveted underneath the joint sleeper directly below the rails, tend to resist their longitudinal displacement. In the sleepers on either side of the joint there is a peculiarity; the rail being fastened by means of a special stop block *p'* (figs. 5, 6, 16, 25), which is inserted in the notch on the inside of the foot of the rail.

The rails, originally intended to be used with wooden sleepers, have two notches *e*, *e* (fig. 6), which are not opposite to each other; the two on the inside into which the stop blocks are inserted are placed in a line obliquely to the axis of the rail (fig. 22); the sleeper therefore presents the same obliquity relatively to this axis (fig. 22), as well as to its two bed plates, necessarily at right angles to the rail or nearly so, and which are hence put in on the skew (figs. 4 and 6).

When the rail is laid on wood sleepers, the fact of its notches being already made does not necessarily determine the absolute position of the sleeper, which can be placed exactly at right angles to the axis of the rail; while the spikes or screws are driven just where the notches happen to hit. With these metal sleepers this however is not the case, for both the holes in the sleeper and the notches of the rail are previously made; and, as these must correspond exactly with each other, when the position of the rail is fixed, that of the sleeper follows: its obliquity on the line can however be slightly varied.

The following regulations of the Paris and Mediterranean Railway, for laying this kind of permanent way, are extracted from their instructions of the 4th of June 1866.

" Whilst laying a permanent way with iron sleepers the following precautions " must be observed.

" All the sleepers must first be placed in position with the rail upon them, in such " a manner, that the joints of the two lines of rails upon the same joint sleeper must " never pass one another by more than $\frac{3}{4}''$; this can always be effected in curves by " the proper use of shorter (19'.6") rails.

" The rails and sleepers being put in position, the stop blocks and the keys of the " joint sleepers are first placed, and then those of the intermediate ones : the two " sleepers on either side of the joint are then shifted until their notches correspond " with those of the foot of the rail, and allow of the insertion of the spikes and the " keys. At the same time the fish-plates are put in position and bolted on; the bolts " and keys however should at this stage be only slightly tightened.

" The packing up may then be proceeded with, which ought to be done simulta- " neously under both ends of the sleeper, and also both inside and outside of the " line at the same time; care should be taken, when one sleeper is packed, not to " pack the adjacent ones up too much, as this would lift it and hinder it from bearing " properly on the ballast.

" When the packing is finished the keys and bolts may be tightened up, but " this operation, like every thing else connected with the permanent way, should be " done carefully; if fastened too tight, more harm than good is done.

" The outside of the line on either side should be covered up with ballast, but " between the rails it should be only up to the level of the top of the sleepers; when " iron sleepers are substituted for wooden ones there will generally be a deficiency " of ballast, and a certain quantity will require to be brought. From time to time the " keys, which have acquired a certain amount of play, should be tightened up; and " each time any repairs are made, it should be noted whether the packing up has " loosened or shaken out any of the keys.

" These keys are drawn with double pronged pliers, as are used with spikes.

The joint sleepers weigh 120lbs and cost 11s 8d; intermediate ones 85lbs and 8s 2d; and 88lbs and 8s 4d for those on either side of the joint.

186. *Eastern of France Railway sleepers.* — While experimenting upon the Fraisans type (185) this Company also tried another form of sleeper, designed by its own engineers, which differs from the preceding, by the absence of the bed-plate, and by the mode of fixing the rail (Pl. XI, figs. 8 to 26). The inclination, $\frac{1}{20}$, is given by the longitudinal curvature of the sleeper (figs. 12 and 18); the outside edge of the foot of the rail is inserted under a riveted clasp, *a*, (figs. 8, 9, 13, 14, 20 and 21), and the inside one is kept down by a bolted cast clip *c* (figs. 8, 13, 19). The absence of the bed-plate is compensated more or less completely by a slightly increased thickness of the flat surface of the sleeper; it is 2″ broad in the intermediate sleepers, in the joint ones (figs. 10 and 15) it ought to be double, which will obviate strengthening them by special pieces, as in the Fraisans sleepers. A thin wrought iron plate *f*, *f*, (figs. 11, 12, 17, 18, 25, 26) fixed by the clasps *α*, *α*, riveted to the sleeper, prevents its longitudinal displacement; as this plate projects sideways beyond the sleeper (fig. 16), it forms a powerful end stop : the figures show one at each end, but in practice it has been applied to only one, and it is found sufficient. The length of the sleeper, which was intended to have been 7′ 6″, has been lengthened to 7′ 10″.

This system has been on trial, since the latter months of 1865, on the Paris to Strasburg, and the Paris to Mulhousen Railways : the intermediate sleepers only are made of iron, they weigh 108^{lbs}, of which 7^{lbs} are due to accessories; the joint sleepers are of wood, as the manufacture of iron joint ones has been postponed until experience has pronounced on the value of the system.

The following letter by the permanent way engineers of the Eastern of France line on the method in question will be read with interest.

" Wooden sleepers offer a resistance to deflexion sufficient for the uniform distri-" bution of the load over the ballast.

" Supposing, therefore, that the pressure of a wheel, loaded with 7 tons, is dis-" tributed over the ballast at the rate of 70^{lbs} per square inch, it is found that the " coefficient of resistance of an intermediate wooden sleeper, 8″ by 5″, is $12\frac{3}{4}^{cwt}$ per " square inch. The iron sleepers ought therefore to afford the same resistance ; it is this " consideration, that conduced to the form of section proposed for the intermediate " sleeper. Calculated on the same hypothesis, the coefficient of resistance of this sleeper " would be nearly 7 tons per square inch; that is to say, about the same as for " the rails. The resistance in the plan of the section to the pressure from below of " the ballast, which tends to produce a flattening of the section, is similarly 7 tons " nearly.

" The joint sleeper is broader than the intermediate, in order to receive the fasten-" ings of the two consecutive rails.

" It is in order to reduce as much as possible the mean weight of the sleepers, that " different types have been admitted for the joint, and for the intermediate ones.

" Wooden sleepers generally have a minimum length of 8'.2", but owing to defects " in them, it is often found necessary to adze them at unequal distances from the " ends, which may be split or damaged; hence it has been considered possible to " reduce to 7'.7" the length of iron sleepers.

" The fastenings of the rail are of two kinds. The outside ones consist of clasps " riveted to, and forming part of the sleeper; with this arrangement the sleepers " may be covered up with ballast on the outside of the line The inside fastenings " are so disposed as to be easily taken out and replaced, without there being any " necessity to remove or uncover the sleeper. They are formed of bolts and clips; " the bolts have flat heads, made to pass through a rectangular opening in the " sleeper; the body of the bolt once fitted into this opening, it only needs a quarter " turn to make the head clip the underside of the sleeper; a portion of the body of " the bolt being made square then prevents it from turning. The clip at the bottom " projects down into the bolt hole in order to resist the interior thrust, caused by the " tendency of the Vignoles rails to straighten themselves in curves. The ends of the " rails at the edge of the foot have notches into which the joint clasps fit, and thus " prevent any longitudinal slipping.

" The mean weight of the joint and of the intermediate sleepers is 100^{lbs} each with " its clasps and end stops complete; it is impossible to ascertain the exact price, but " approximately it may be reckoned at about £ 8.0.0 per ton, the rails costing a " little over £ 7.0.0; a sleeper would therefore be worth about 7^s. The mean cost of a " wooden sleeper, including adzing, boring, and tarring, is 4^s 8^d.

" If a wooden sleeper lasts at most fifteen years, the annual expense for the ma- " terials, exclusive of the labour of the maintenance, would be.

" Interest and redemption of capital of first outlay. . . .	4^{s}8^d × 0.0565 = 3^d	
" Renewal.	4^s 8^d	
Value of old sleeper to be deducted.	10^d	
" Remains.	3^s 10^d	
" Of which $\frac{1}{15}$ annually.		3^d
" Total annual cost of wood sleeper..		6^d

" The duration of an iron sleeper cannot as yet be estimated even approximately; " but supposing it to be only double that of a wooden one, or thirty years, we have " annually.

" Interest and redemption.	7^s × 0.0565 = 4 $\frac{3}{4}$^{d}	
" Renewal.	7^s 0^d	
" Value of old sleeper (100$^{lbs.}$ at $\frac{1}{2}$^{d}) to be deducted	4^s 2^d	
" Remains.	3^s 10^d	
" Of which $\frac{1}{30}$ to be added each year.		1 $\frac{1}{8}$^{d}
" Total annual cost of metal sleeper.		6^d nearly.

" There would not consequently be any great economy at present in the use of " wrought iron sleepers; but if the increase in the price of wood, and the diminution " in that of iron continues, as has been the case for the last few years, the " employment of iron sleepers may become advantageous. "

187. The Northern of France Railway is about making an important trial of them; the form selected differs from that of the Lyons Railway only in the slightly diminished weight of the sleeper, and by the suppression of the bed plate; the inclination is given by the sleeper itself, which is curved while hot, towards the centre.

This arrangement is similar to that of the Eastern of France Railway; almost the only difference being, that the outside fastenings, like the inside ones, consist of a wedge-block and key; by which means, without the addition of any special pieces, the extra width required in the curves can be given (*).

188. Mr Ed. Wilson has lately applied on the Lucknow and Cawnpore section of the Indian Branch Railway (a line which as we have already seen (9) has been altered from the 4'.0" to the 5'. 3" gauge) a special form for the supports (Pl. IX, figs. 1, 2, 3); having to iron sleepers the same relation, that the chair-plates of Mr Pouillet bear to wooden ones.

The bearing surface is formed of corrugated sheet iron, only $\frac{1}{8}$" thick; the corrugations are of but little depth, yet sufficiently so to augment considerably the moment of inertia, relatively to the axis passing through the half height, and consequently the rigidity of the mass: the thinness of the metal, as well as the smallness in depth of the sleeper, are however compensated for by its great breadth, distributing over a large bearing surface the pressure of the rail upon the sleeper, and that of the sleeper upon the ballast. Each bearer, weighing about 11lbs, has three corrugations, K, K, K, running crosswise, upon each of which the rail rests; but it is fixed to the centre one only by means of two large headed screws, *v*, *v*, having the plate P as a kind of fixed nut. This corrugation is covered and strengthened by the cap *t*, *t*, which forms the real sleeper; its depth is consequently rather less than that of the other two.

The three rolls of the bearer, as well as the covering cap itself, oppose to the longitudinal movement of the rails the resistance of a considerable surface of ballast; the lateral thrust hardly seems sufficient, especially on a line with curves of only 14 chains radius; this might however be easily augmented at a very little expense, as in the sleepers of the Eastern of France (186), by making use of the total end surface of the supports. These

(*) A system of metal sleepers, with the details of which I am unacquainted, has been tried on the Portuguese railways; but the results were unsatisfactory, owing apparently to the thinness of the iron employed.

A form of wrought iron sleeper, invented by Messrs. Shanks and Nelson, is also being tried in India, of which likewise I have no details; the method of fastening seems however to have nothing new in it, as the double-headed rail and chair are preserved; the spikes are replaced by bolts and nuts.

are however very close to one another, the distance between their centres being only 2'.6". The sleeper when complete, composed of two corrugated bearers, and of the covering cap and its accessories, weighs only 40lbs.

This arrangement is certainly a very ingenious one; it may however be doubted whether the elements are not too light, and whether these broad and slender bearers might not soon bend and give way.

There are no joint sleepers used; for the rails, as already described (57), have their joints unsupported (74), and fastened with steel fish-plates doubling down under the rail (104) (Pl. X, figs. 1 and 2).

189. Iron sleepers are quite as stable as any others; the experiment made on the Eastern of France Railway, at points where the speed was high and the circulation very considerable, are conclusive upon this head; but they require, it is true, a ballast suited to them, where the gravel contains a small quantity of clay to give it some binding power. The packing which is done with an ordinary pick, then soon forms a mass, which fills up the hollow of the sleeper, receives and transmits the pressure, acts in unison with the metal, and thus supplies any want of body in the sleeper. When used with a suitable ballast, the mistrust at first inspired (184) by the thinness of these supports appears therefore to be without foundation. Perhaps however the objection may exist in full force, if a ballast of broken stones only can be used.

Experience also appears to show that metallic supports, when embedded in the ballast are very slightly attacked by oxydation; participating therefore, despite of the still more unfavourable conditions in which they are placed, in the immunity which the rails enjoy, and which is due to the vibrations produced by the passing trains.

This fact is of vital importance; for if rust attacked even slowly the bearers, and the pieces fastening down the rail, the whole would soon become worthless on account of the thinness of the metal.

§ III. — Third Class. Continuous Longitudinal Supports.

190. It is in England especially that this form of permanent way, entirely metallic, has been for several years experimented upon. It will suffice, as an example, to mention Mr Mc Donnell's system, which has been applied since 1853 with successive modifications upon the Bristol and Exeter line, in conjunction with the bridge rail (55). In one of the first types made (Pl. IX, fig. 14) the lon-

gitudinal, *l*, slightly arched in its cross section, was $\frac{11}{16}''$ thick and 11″ broad; its upper side had two projections corresponding to the edges of the foot of the rail, and a rib *n*, which fitted into the hollow of the rail; a species of saddle-plate *s*, weighing about 56^{lbs} was placed underneath at each joint of the longitudinal. The whole was made fast by bolts with the nuts uppermost. Packing pieces of creosoted fir *b*, $\frac{1}{4}''$ in thickness, were placed between the rail and the longitudinal; four bolts were used at the joints of the longitudinals, and eight at those of the rail, the holes of which were oval for expansion.

The two lines of rails were tied together by angle irons 12 feet apart, and fixed by bolts passing through the longitudinal and the rail.

2nd *Type.* Experience having shown, that it would be better to increase the bearing surface on the ballast, the breadth of the longitudinal was made 12″, but at the same time the thickness was reduced to $\frac{9}{16}''$ (fig. 15). The joint saddle-plate, *s*, instead of projecting beyond and enclosing the longitudinal, was made even somewhat narrower than it; but at the same time a spur, *c*, projecting downward was added, to stiffen it, and develop the lateral thrust of the ballast.

Besides the cross pieces every 12 feet, as in the preceding case, tying together the two lines of rail, both lines of way were themselves fastened together with ties at every 24 feet; thus augmenting the transverse resistance.

3rd *Type.* In a second modification made in 1859 the transverse curvature of the longitudinal, and consequently that of the joint saddle-plate, was done away with, owing to the difficulties in rolling them, which iron founders alleged the former form occasioned; also the breadth of the saddle-plate was reduced still further to 8″, whilst that of the longitudinal was increased to 13″ (fig. 16).

With this third shape an inclination, as already mentioned (56), of $\frac{1}{24}$ was given to the rail, which previously had been vertical.

4th *Type.* The last alteration was made in 1860, and consists principally in the suppression of the joint plate of the longitudinal, which was transferred to the rail joint (fig. 17). It is in this form, that the system has been tried, but with little success, on the Bridport Railway; this is mainly attributed to the weakness of the component parts (the longitudinals weighed only 60^{lbs} per yard run), to the steepness of the inclines, 1 in 50, and to the ballast being composed of broken stones of large size only.

But, even allowing for the influence of these causes, it is difficult to consider the principle as perfect, especially when it is remembered how many trials, both prolonged and varied, have ended only in its application to a very little extent. Though the rail here treated of is the bridge one, the exposition of the details of

the system is not quite useless; as, had the experiment answered, it would have been easy to apply it to the Vignoles rail.

191. Previous to the events, which led to the annexation of the Duchy of Nassau to Prussia, the government had decided upon the trial on the State Railway of a system proposed by Mr Hilf, one of its Engineers (Pl. VIII, fig. 28).

An inverted ⊤ rail is riveted on to a broad longitudinal with three ribs *c, c, c,* projecting downwards, intended to increase both the rigidity and the lateral thrust; the two lines of rail are tied together by angle-irons, T, bolted on to the longitudinal, but in fact too low to maintain the inclination.

This composite rail besides would be heavy, costly, and with all but little effective according to appearances. It is too low; and moreover the loosening of the rivets *r, r,* seems to be unavoidable.

§ IV. — Fourth Class. Rails laid directly upon the ballast.

192. *Barlow Rails* (Pl IX, fig. 23). To give to the rail sufficient breadth of base, and stiffness enough to dispense with any special supports; to tie together the two lines of rails merely by cross ties, which preserve the gauge and the inclination; and to immerse the whole in the ballast to a depth sufficient to do away with the effects of expansion; such is the system proposed by Mr Barlow, and which he seemed at first to have succeeded in, judging from the experiments made in England. Some French engineers also held the same opinion.

The directors of the Southern Railway of France, having determined to adopt the Barlow rail for their line from Bordeaux to Cette, justified to their shareholders the grave step which they had taken in the following terms.

" Convinced of the inconveniences, which have been ascertained during the last " few years to exist, in the system of permanent way used exclusively in France, and " being desirous of placing the whole of our line in a condition, such as to ensure " a great economy combined with an active circulation, we have been induced to " enter largely into that system of permanent way with longitudinal supports, the " superiority of which has actually been confirmed in England by a long expe- " rience. "

After the last assertion, somewhat hasardous at least when stated in such absolute terms, comes the enumeration of the advantages attributed to the system spoken of; viz.,

" Economy in the expenses of the first laying, compared with the ordinary cross " sleeper system, when the expenses of maintenance and of renewals are also taken

" into account; rigidity of the joints, causing the up and down movement to disap-
" pear; simplicity in laying down and in maintenance, resulting from the diminution
" in the number of pieces, and from the way of laying the ballast; preservation of
" the rolling stock; and lastly security to the traffic, no longer endangered by frac-
" tures of the rails or of their bearers. "

The proposition, founded on arguments apparently unanswerable, was fully and entirely carried out.

Some years later there was not between Bordeaux and Cette a single Barlow rail; the contracts for the supply of these rails were annulled; and, after many mistakes, they returned not even to the inverted ⊤ rail on cross sleepers, but simply to the chair-rail.

The Southern of France Railway Company had therefore been too hasty; it recognized though somewhat tardily, that it would have considerably to lower its first opinion of the system; and that, at the period when it flattered itself it was making great progress, other Railway Companies had not done ill by simply adhering to the beaten track. We must not however misunderstand the causes of this sudden retrogression. Mr Barlow's permanent way is undoubtedly very good, very smooth travelling, and easy of maintenance; it kept well packed up; even to replace a rail was a simple operation in the hands of a workman, though a skilled one, it is true; experience moreover has fully confirmed the ideas of the inventor regarding the invariability of the joints, and more strongly than even Mr Barlow himself would have hoped for, under a sun so intense as that of the South of France.

On the Bordeaux and Toulouse line neither the fractures, nor the undulations, either sideways or vertically, of the rails on the longitudinals were remarked, as on the Bayonne line; this may be explained by the fact of the rail being almost entirely embedded in the ballast, thus withdrawing it in great part from insolation; and also by the conductibility due to the thinness of the metal, and to the large surface of ballast, both inside and out, with which it was in contact. It is allowed, that on the Southern of France line the difference between the extremes of temperature may amount to 126° for rails exposed freely to the open air; but it is clear that the extremes are much less for the Barlow rails, when laid in place.

In fact it is not among the faults inherent to the principle of its construction, that we must look for the causes of the failure of this rail. Experience has even proved favourable to it in several ways; thus it has not a tendency to open out under its load, as was feared. It was supposed that the packing could not remain in the inside on account of the vibrations, and that the rails would bear only upon its two jaws. Mr Brunel, who applied the system on a

large scale, considers that there is no foundation for the fear; as it is easy to pack the ballast, provided it is gravel, into the hollow of the rail, so that it soon forms a solid mass upon which the rail rests. This assertion has been fully confirmed by facts observed on the Southern of France railway; the maintenance, at first rather laborious, became very easy as soon as by repeated packing this mass had commenced to form.

The want of thrust in the rail also occupied their attention, tending, it was said, to act laterally upon the ballast in the same manner as a plough share does; instances of this kind had at times occurred in England, sufficiently grave to cause the depth of the rail to be increased at the expense of its breadth, as did Mr Brunel on the West Cornwall line.

The insufficiency of the angle iron cross ties, turned up at the ends to give the inclination, being hardly rigid enough, had even induced Mr Barlow to try the rail on wooden cross sleepers (Pl. IX, fig. 22); but thus to abandon its characteristic property is certainly to condemn the system. It has since been proposed to use as cross ties short lengths of rail inverted. Moreover on the Southern of France line none of the inconveniences were remarked, which the above expedients were intended to counteract; viz., the tendency of the rail to overturn, and the fracture of the rivets of the cross ties. The only fact noticed was, that the joint pieces were too weak; the rivets on each side of the joint, of which there were only four, were consequently increased to six. The objection of excessive rigidity raised by some engineers, appears to be without foundation.

The principal objection is the rapid destruction of the rails, which crush and peel away at the top; the excess of the convexity, and of the load per axle do not alone explain this prompt disorganisation, as single and double headed rails have under the same circumstances not been nearly so rapidly destroyed. The true influence of these exaggerations however is very clear, and, as far as regards the Barlow rail, is proved by an undeniable fact, if doubt is possible in the case.

The first trials in France took place simultaneously in 1852, one on the Northern line at La Chapelle, the other upon the up line of the Saint Germain railway near the Route de la Révolte. The rails were of English make, from the same foundry, and made at the same time; at the end of barely 15 months the rails on the Northern line, completely crushed by the constant circulation of the heavy engines with coupled wheels in use on this line, had all disappeared; whilst on the Saint Germain railway after five years wear, with an equally active traffic but with a more moderate load per axle, every fourth one was still in its place and in good condition.

The French-made rails on the Southern of France line were undoubtedly very middling in quality, but it would be unjust to lay the whole cause of the failure to these foundries. The English rails, from foundries accustomed to their manufacture, Tredegar and Dowlais, were much better, but still were far from perfect.

The system of permanent way, so cordially received, so highly supported, and the application of which had spread so rapidly in England, 700 to 800 miles of single way, was just as quickly abandoned. It was considered, that the drawback of a more difficult and costly process of manufacture, requiring more powerful machines, would have been amply compensated for by the manifest advantages of the rail, had it accomplished the service it might certainly have been expected to perform. But in England as in France these presupposed calculations have been entirely upset by the rapid deterioration of the rails, as if their very form contained some principle of destruction.

This principle exists less in the form, than in a kind of antagonism between it and its method of manufacture, which excludes hard iron, the only kind suitable for making rails. With the ordinary sections it is only during the first process, that the bar is rolled out both flatwise and upright, the finishing rolls are always laid flatwise; on this account double headed rails are easier to roll, inverted T rails, and especially bridge rails, are less so in proportion as the foot is broader and thinner; with the Barlow rail the finishing rolls are much deeper, than with the other sections. Thus the same cross section of a bar is acted upon by cylinders driven at very different degrees of velocity. Hence arise slippings which absorb a considerable motive power, even when these are moderate and the cylinders are of large diameter; entailing moreover numerous cracks and flaws, if care was not taken to use iron which is soft and flexible, and by this very fact but little fitted to resist the wear which the rails ought to undergo.

The form of the Barlow rail seems, to me at least, better suited to another method of manufacture, which would allow of the use of hard iron, and at the same time free the foundries from the costly obligation of doubling the motive power of the rolls. The series of transformations which the pile undergoes amounts in fact to the two following. 1st The production of a broad bar, thicker in the middle of its cross section; 2nd the inflection of this bar transversely without altering its thickness. These two effects instead of being produced simultaneously by the rolls, at the cost of serious inconveniences and difficulties, might be obtained one after the other. The rolls would be required to distribute the thickness, which is especially their duty; and from the press, acting successively on its whole length, the bending thereof would

be demanded. Thus a nearly flat bar might be rolled out without being exposed to those slips. which iron cannot endure without receiving rents and cracks, except it is of so soft and ductile a quality as by this very fact to render it useless for the manufacture of rails.

In proportion to the eagerness and unreflective rapidity with which the Barlow rail was taken up, so was the discouragement with it complete; the principle was condemned without inquiry, as to whether it really was the cause of the non-success of the system. Where however is there a new principle, that succeeds at the first attempt, or that finds immediately its true practical formula?

193. *Mr Hartwich's rail.* — If one of the principal objections to the Barlow rail is its form, owing to its difficulty of being rolled properly, Mr Hartwich's rail (Pl. IX, figs. 4 to 13) completely does away with the difficulty; since the breadth of both head and foot do not exceed that of the ordinary inverted T rails, or at least the difficulty of manufacture only increases proportionately with the augmentation of the weight of the pile; an increase which is requisite, as the length of the bars cannot be reduced and the joints augmented without great inconvenience. This augmentation in the weight, corresponding only to a greater height of web, is but of small moment when compared with the advantages which it appears to carry with it. In fact the key of the system lies in this increase in the height; to it also is it due, that the rail can dispense with all support.

The Prussian Ministerial rail is $5\frac{1}{8}''$ in depth; Mr Hartwich retains the dimension of its head and foot, but increases only the depth to $11\frac{1}{2}''$; the weight increasing in the ratio of 1 to 1.56 (fig. 4), while the the momentum of resistance is quadrupled. It is not therefore by an increased breadth of base, that the author distributes the pressure over a sufficient surface : but it is in reality by lengthening it, effectively obtained by adding to the depth, and by the additional rigidity which hence results to the rail.

Nothing can be more correct than this idea; it is in perfect conformity with the principle of judicious and economical employment of materials. Instability and a tendency to bend over might, it is true, be feared in so deep a rail; but these must be provided against by cross ties, to the arrangement of which experience alone can guide us. The two lines of rails are connected together by two rows of round bars *t*, *t*, having the ends screw-cut, these portions are bent perpendicularly to the rail, which is inclined to $\frac{1}{16}$; the nuts *m*, *m*, placed both on the inside and the outside of the rail, allow of the gauge, and the inclination being easily regulated.

The joints are rendered rigid by fish-plates *e*, *e*, and by a bed plate *p*, *p*, fastened by six bolts to as many clips *t*, *t*, *t*, which grip the foot of the rail; the bolts fit into the notches *x*, *x* (fig. 11) in order to maintain without variation the position of the bed-plate relatively to the rail. On account of the great depth the fish-plate bolts are in two rows, four above and four below. The cross rods *t*, 1" in diameter, are placed six to each 21'.8" rail.

As with the Barlow, and still more with Mr Hartwich's rail, in proportion as it is embedded in the ballast (fig. 13), so is it removed from the influence and the variations of temperature; lateral thrust is also amply provided for; the same may not however be the case as regards resistance to longitudinal displacement, which is only counterbalanced by the friction of the ballast, over a considerable surface it is true. In case of need an upright plate might be attached at certain distances to the cross rods; experience however does not seem to have shown the necessity for any special stop pieces.

The rail having a flat base, and not requiring any packing up into a hollow, nor the formation of any supporting mass, ought on this account to be easily used with a ballast of broken stones; it is hardly necessary to dwell upon the importance of this fact.

Two portions, each 750 yards long, on an incline of 1 in 71, and on a curve of 35 chains radius, have been laid down on the Rhenish Railway; one on the Coblentz and Oberlanhnstein line, the other upon that from Euskirchen to Mechernich. The difficulty of being rolled without special apparatus did not allow the rails to be more than 18'.6" in length. The trains, with tank engines weighing 37 tons, travel at the rate of 30 miles per hour.

As far as can be judged from an experience of only two years the arrangement designed by Mr Hartwich has realized its object, and entirely done away with the use of timber without in any way sacrificing, indeed far from it, any of the advantages which were considered indispensable in the employment of wood.

Mr Hartwich states that the rail $11\frac{1}{2}$" deep is stronger than necessary, and, provided the ballast be of good quality, that the depth may be reduced to $9\frac{1}{2}$", which would render the cost of this system of permanent way the same as that of the wooden cross sleeper one. The author shows, as is in fact a very natural consequence, a very perceptible economy of ballast. As the labour of maintenance, as well as the packing, instead of occupying the whole breadth of formation, is necessitated merely in a narrow belt directly round each rail, the ballasting might for each line be limited to two longitudinal trenches L, L, only wide enough to allow of working without mixing up the ballast with the surrounding earth (fig. 13); some drainage is then requisite to keep them dry.

Even if experience were to condemn this arrangement of a detail, and conduced rather to preserve the ballast undiminished in quantity, it is still clear, that the system would thence have received no check, if its capital advantages are confirmed by it.

194. *Composite rails.*— These are a consequence of Mr Barlow's form of rail, and have been proposed by himself (Pl. IX, figs. 18, 19, 20); their manufacture in one piece was abandoned, to avoid the difficulties which occurred in making a rail so considerable both in depth and in width; whether, as with the Barlow rail, it be in a saddle form, or whether the body was single. The rail is therefore formed only of pieces easy to roll, and joined together by bolts or by rivets. If the inconveniences and complications of these assemblages cannot be denied, on the other hand, as much more than compensating for them, are adduced the advantages already mentioned (99), of the complete separation of the head, the only part which wears out; thus allowing of its being replaced, or of manufacturing it alone of steel.

The rail proposed by Mr de Waldegg (Pl. X, fig. 27) is merely a Barlow rail composed of a head and two open wings; the whole fastened together by rivets. There is no necessity to detail this project, which up to the present has had no application.

195. *Lines of the Union of the North of Germany.* — The Directors of these Railways agreed in 1863 to experiment upon a metallic system of permanent way. They adopted as a general type an unsupported rail, composed essentially of a head (" Kopfschiene" or " Oberschiene "), and of two angle irons (" Unterschiene"), forming the deep web and the broad base of the rail; cross ties connect the two lines of rails together.

The particular types differ not only in height and in breadth, but also by the greater or less angle of aperture between the sides of each angle-iron, and more especially by the position and method of fastening of the cross ties.

1st. *Brunswick.*—The Brunswick Railway, following the advice of Mr Scheffler, has applied the three forms shown in (Pl. VIII, figs. 18 to 27). In type N° 1 (figs. 18, 20, 21) the cross ties, T, were placed under the rail, similarly to cross sleepers; this similarity does not exist however in any great degree, for where a rail is sufficiently rigid to be placed directly upon the ballast, and that it is no longer a question of dividing it into spans by the supports, but only of resisting horizontal strains, then the cross ties ought evidently to be brought nearer to the point of application of these strains; viz., the head of the rail. The same may be said of these cross ties of type N° 1, as of the wooden cross pieces used with timber longitudinal sleepers (123).

The cross ties T being horizontal, the inclination is given to the rail by the angle-irons: two kinds of these are therefore required, one acute-angled for the inside of the line; the other obtuse-angled for the outside (fig. 18).

In type N° 2 (figs. 22 to 25) the cross ties θ, 4′ 8″ apart, are riveted to the upright limb of both angle-irons, with a packing piece, *f*, between them. In type N° 3 (figs. 26 and 27), they are channel irons turned down at each end, and fixed by four bolts F.

In all three types the joints of the angle-irons have a bed-plate, or inferior cover joint P, bolted to them; the holes in the rail being oval. The joints of the head require no additional pieces, the angle-irons acting as cover joints.

In N° 3 type the rivets are all replaced by bolts; the one which fixes the head (B, fig. 27), is conical, in order to act at the same time as a wedge-key upon the head, and to keep it in its place on the bearings on the top of the angle-irons, which are widened out for the purpose.

Types 1 and 2 have been laid side by side, one on one line, the other on the other, on a section having much traffic between Brunswick and Wolfenbuttel. The permanent way laid in this manner, and ballasted with coarse gravel, is good; it appears to suffer even less than the common wooden cross-sleeper system during the suspension of maintenance in prolonged periods of cold. The bolts, the loosening of which might have been feared, act very well, and appear therefore preferable to rivets, which are always a drawback in the maintenance.

It is not yet possible to give any formal decision as to the result of an experiment, which only has been tried since the end of 1864. The third type has been even a shorter time still upon trial; it has been placed, and properly so, upon a curve.

The "Oberschiene," or head, is nearly free from oxydation, but this exemption does not appear to be quite so complete for the "Unterschiene," or body of the rail; however it is very much less attacked by rust, than are the ordinary rails not run over by trains. On this head, the result appears to be a little less satisfactory with the Brunswick composite rails, than with the metallic cross sleepers tried in France (189).

2nd. *Hanover. — Cologne and Minden.* — The type tried on the Hanoverian Railways, and on Cologne and Minden line (figs. 14 to 17), is analogous to Nos 2 and 3 of the Brunswick ones.

It differs only, 1st by the more obtuse angle between the two limbs of each angle-iron, and by the saddle-back shape of the inferior cover joint P; the rail also presents a saddle form, which is favourable to its stability; 2nd by the section of the angle-iron cover joint; the vertical limb P augments its stiffness,

and, which is no doubt the essential point, it is suited to counteract any tendency of the rail to longitudinal dragging (105); 3rd by the riveting of the cover joint upon the inside angle-iron, the outside angle-iron being the only one bolted; 4th by the double duty of the upper bolt, *b* (fig. 15), which serves at the same time to fix both the head, A, and the cross piece, *t*, close to it.

The cross ties are 10 feet apart. The bolts fastening the head are placed in pairs (fig. 17), the same arrangement as in type N° 3 of the Brunswick lines; their long pyramidical head B (fig. 14), pressing at *m* the body of the rail, and at *p* and *q* the angle-irons, acts as a key; this is a real improvement, yet hardly perhaps a sufficient one.

A first trial on a distance of 1600 yards having given satisfactory results, the system has now been laid on another similar length.

3rd. ***Wurtemberg; Aix la Chapelle Dusseldorf and Ruhrort; Oppeln to Tarnowitz.*** —The arrangement tried upon these lines is that of Messrs. Köstlin and Battig of Vienna (Pl. VIII, figs. 12, 13 and 29, and Pl. IX, fig. 28); it is characterized by the saddle shape of the composite rail, and by the position underneath of the cross ties, single or double ⊤ irons; the head and the angle-iron wings are of the same length 22'.6" (24 Schuh); the joints of these three pieces, being equally divided, are therefore 7'.6" apart. The interval between the cross ties, is also the same; so that there is one at each joint, whether of the head or of the angle-irons.

All the joints are free to expand, a condition which is looked upon as necessary by the authors, not only for the head but also for the angles, connected together by means of the cross ties. The substitution of bolts instead of rivets (fig. 29) guarantees this liberty for the head, but hardly so for the angles, as the ballast must soon choke up, and nullify any excess of size in the holes; the variations of temperature ought however to be slight for metal so thin, and protected by the ballast.

The holes in the body of the rail are horizontally oval, but vertically their height is necessarily equal to the diameter of the bolt. It remains to be seen if this suffices to ensure the application of the head upon its bearings; the authors themselves appear to be doubtful on this point, for they proposed to replace the bolts by rivets, put in very hot, of a diameter rather larger than the height of the oval hole; and which would therefore be forced to expand horizontally, without obstructing it completely. This may perhaps be better than the bolt; but even without taking into consideration the enormous resistance developed by the friction of the rivet, which might in fact amount to the total suppression of play, this can doubtless be only a temporary expedient. If the fishplate bolts resist so well, it is on account of the body never being touched by

the rail; and that they work only in tension. The bolts of the composite rail are under very different conditions; and it is to be feared that the jamming of the surfaces together, and the continual series of slight shocks between the stem of the rail and the body of the bolts, might soon cause a separation between them. It appears therefore to be indispensable that the body of the rail should be tightened up by a wedge shaped key, as has just been shown.

The original design (Pl. VIII, fig. 29) has received a few modifications suggested by experience; the depth has been somewhat augmented, and rivets have been substituted for bolts in the connection of the cross ties with the rail (fig. 12): the contrary was done in Brunswick, and probably with good reason.

196. Mr W. Jordan of Göttingen has turned his attention, and not without reason, to the danger of the imperfect application of the head of the rail upon its bearings, the result of which would be an up and down movement, similar to that of the double headed rail and the foot of its chair (39). The proposal of Mr Jordan to avoid this serious inconvenience is shown in fig. 28, Pl. X.; it consists, as may be seen at once, in transforming the angle-irons into veritable angle-iron fish-plates with the lower limb much elongated, and griping a double headed rail, which allows of being turned. As the two inclined bearings of the angle-irons, when tightened by the bolts, work only in tension, they ensure a close contact between the rail and its immediate supports; but the author only obtains this advantage by adding to the rail a lower head, which is almost useless as far as regards the resistance of the system.

This advantage though real is purchased at too great a cost; and hence we can understand up to a certain point why Mr Jordan has endeavoured to utilize this increase of weight by turning the rail, and consequently has adopted the symmetrical double headed one. This does not however justify by any means the great weight of the whole system.

Mr Mazilier had before this already shown an arrangement, which only differed from the preceding in the rectangular shape of the angle-irons forming the fish-plate and the base; by making the angle obtuse Mr Jordan improves the rigidity of the composite rail, as well as its lateral thrust; which is something but not sufficient to render the principle acceptable.

197. Figs. 24 to 27, Pl. IX, represent two forms of composite rails proposed by Mr H. Scheffler. The first (fig. 24) relieves the sides of the head from the load, which is transferred to the base of the "Kopfschiene" A. The "Unterschiene" is then formed of a single T iron, bent in its upper portion B. The second type is analogous to those just described, almost the only difference

being the great depth of the head; it appears moreover inferior to the Hanoverian, and to the Cologne and Minden models (Pl. VIII, figs. 14 to 17).

198. In fact, the question of the suppression of wood is now being studied with increased zeal in Germany, in France and in India. It is felt, that it is absolutely necessary to succeed in doing so; and, judging from the results already obtained, and particularly from the low price of iron, it is extremely probable that this will be effected. One cannot as yet hazard any opinion as to the merit of the several systems now before us; nevertheless Mr Hartwich's rail appears to have the greatest chance of success, and the least of all those composite rails, which are connected together by rivets or with bolts. Besides these various systems of metallic permanent way have all of them, Mr Hartwich's alone excepted, to be made adaptable to a ballast of broken stones the only sort that can in many cases be obtained.

CHAPTER IX.

SPECIAL POINTS IN THE PERMANENT WAY.

The arrangement of the various elements of the permanent way ought be somewhat modified, 1st in curves; 2nd at certain works of art; 3rd at road crossings; 4th where railways cross one another; and 5th where moveable apparatus are necessary to allow entire trains or single carriages to pass from one line to another.

In the same chapter will be described two subjects, which ought naturally to be included in the study of the permanent way : namely, the arrangements which do away with any change of carriage in crossing broad watercourses, and the connection of mineral and other private manufacturing branches.

§ I. — Modifications in Curves.

199. *Play of the line.* If each pair of wheels formed a revolving cone, having its summit at the centre of the curve, and was acted upon, in consequence of the reaction of the two rails not being alike, by a centripetal force equal to the centrifugal one corresponding to the speed and to the radius of the curve, then the movement in curves would take place freely, that is without any other resistance than would occur on a straight.

This ideal situation may be more or less approached by modifying the rolling stock, and the permanent way : at present we shall only examine the question in this latter light, supposing that the rolling stock is constructed to suit straights only; viz., with axles invariably parallel, and with slightly conical tyres, about $\frac{1}{20}$ (55 etc.).

The first condition is evidently, that the flanges of the wheels may be inscribed between the rails, not only without tension, without the system being forced, in a state of repose, but also without contact and even with a certain amount of play.

If a carriage, with its axles apart a distance d, be placed on the line on a straight exactly in the mean position, each axle can be displaced at right angles to the line a certain distance $\frac{j}{2}$; j is termed *the play of the line.*

If the line be supposed to curve in a series of arcs of successively decreasing radii, yet always having its centre on the transverse axis of the carriage, and touching the tyres of the wheels at the same points α, β, γ, δ (Pl. VIII, figs. 7 and 8), the rails will gradually approach nearer and nearer to the flange-lips, and will reach them, when OA (fig. 7) $=$ O′A′ (fig. 8). Let r represent the mean radius of the tyre, m the depth of the flange-lip, ρ the radius of the curve-limit with which contact takes place, and d the distance apart of the axles.

Then (fig. 7) we have

$$AC = AO + \frac{d}{2} = \sqrt{(2\rho - BC)BC} = \sqrt{2\rho \times BC} \text{ nearly;}$$

$$\text{and } AO = A'O' = \sqrt{2rm} \text{ nearly.}$$

$$\text{And since } BC = BD + DC, \quad BD = \frac{d^2}{8\rho}, \quad \text{and } DC = \frac{j}{2},$$

$$\text{we have } \sqrt{2rm} + \frac{d}{2} = \sqrt{2\rho\left(\frac{d^2}{8\rho} + j\right)}; \quad \text{whence } \rho = \frac{1}{j}\left(2rm + d\sqrt{2rm}\right).$$

When therefore $r = 20''$; $m = 1\frac{1}{4}''$; $d = 11'.6''$; and $j = 1''$; then $\rho = 28\frac{1}{2}$ yards.

Then only the play has disappeared, and inscription becomes impossible; there is therefore a margin.

For a radius $\rho' > \rho$ (fig. 9) the half play is diminished only by the quantity by which the rail approaches the flange, viz., to the point A; so that $AO = \sqrt{2rm}$.

Therefore, j' representing the fresh amount of play,

$$\frac{j'}{2} = IA = EC = B'C - B'E = B'D + DC - B'E,$$

$$\text{But } B'D = \frac{d^2}{8\rho'}; \quad DC = \frac{j}{2}; \quad \text{and } B'E = \frac{1}{2\rho'}\left(2rm + d\sqrt{2rm} + \frac{d^2}{4}\right);$$

Inserting these values, and reducing,

$$\text{we have } \frac{j'}{2} = \frac{j}{2} - \frac{1}{2\rho'}\left(2rm + d\sqrt{2rm}\right).$$

It is requisite therefore, in order to preserve, in a curve of the radius ρ', the same play which is considered useful in a straight, to augment the width of the line by

$$j - j' = \frac{1}{\rho'}\, 2 + rm\, d\left(\sqrt{2rm}\right).$$

Besides to ensure the play being actually the same, the rolling stock ought to possess, by the nature of its construction, a tendency to place itself when in curves in the mean position, as it seeks to do in straights. But carriages with parallel axles are inclined in curves on the contrary to assume an oblique position relatively to the chord of the arc they occupy. It is expedient therefore even on this account only, that the extra width should exceed the above amount.

It will moreover suffice here to ascertain this first cause of extra width of the line in curves, an excess which ought to be greater in proportion as the radius of the curve is smaller, and the distance between the axles greater; this however is limited by the breadth of the tyres (*).

The second cause is the conicity, useful within certain limits for locomotion in straights (55 and following), but which it is most expedient to utilize as much as possible in order to facilitate circulation in curves. A pair of wheels, when passing from a straight to a curve, have a tendency to continue in a straight line, and, if the play was null or very slight, the flange of the outside wheel would immediately press against the edge of the rail : when play exists the flange does not come in contact till much later, or perhaps not at all (speaking of one pair of wheels only), if the radius of the curve is large enough. In consequence of the conicity the wheel tyres impinge upon the rails on the outside with a greater radius, and on the inside with a smaller radius than the mean one, and thus by this very fact is the system of a cylinder transformed into that of a rolling cone; but often in an insufficient degree, the summit of this cone being more or less beyond the centre of the curve.

The extra width between the rails in fact is limited by the breadth of the tyres of the wheel, the inside wheel ought to bear sufficiently upon its rail when the fellow wheel has its flange pressed against the outside rail; so that practically the slipping of the tyres is merely attenuated.

The conicity, combined with the augmentation of play, renders another service, though a less one it is true, in consequence of the transverse displacement of the rails relatively to the bi-conical system. The resultant of the reaction of the rails on the wheels, reactions which are non-symmetrical on account of the conicity and of the slight inclination resulting from it for the axle, is slightly inclined upon the vertical; hence arises a centripetal force capable of

(*) According to Mr Bineau "Chemins de fer d'Angleterre," p. 166, the play, uniform throughout in straights and in curves, was about 2" on the English railways. This exceeds the amount now used even in curves; and no doubt it was not surpassed at the period, 1839, at which Mr Binean wrote.

causing equilibrium to the centrifugal force, but only within limits to speed and to radius, which are totally insufficient with the ordinary amount of conicity and of play given to the line.

200. *Cant of the line.* — The above insufficiency is less to be regretted as there is available a method of establishing the equilibrium for limits as high as may be desired; but with this grave inconvenience it is true, that it is suited only to these limits, instead of adapting itself, as the combined action of conicity and a sufficient play would do, to all intermediate degrees. As is well known, the principle applied on railways is to dip the line towards the centre of the curve, and thus to place the carriages upon an inclined plane, upon which they are kept in equilibrium by the action of the centrifugal force and by their own weight; which gives at once for the inclination α of the plane, determined, as it is always done, without taking into account the small centripetal force due to the conicity, the following,

$$\tan \alpha = \frac{eV^2 - g\rho f}{g\rho + fV^2}; \text{ } e \text{ being the width of the line.}$$

Even the friction is neglected, which slightly augments the cant.

The difference of level S between the two rails is therefore

$$S = \frac{eV^2}{g\rho}.$$

The elevation is always calculated for the fastest trains; but, as it is necessarily limited in curves of small radius, the rate also ought to be so as well, if for this motive only : besides security demands it.

In the United States the cant reaches 10″.

Upon the Eastern of France its maximum value is fixed at $3\frac{1}{8}$″, and is regulated,

1st For a speed of 40 miles an hour ($19\frac{1}{2}$ yards per second), on lines travelled over by express and mail trains.

2nd For one of 31 miles an hour (15 yards per second), with mixed trains only on the line.

3rd For the rate of $22\frac{1}{2}$ miles an hour (11 yards per second), in some curves of exceptionally reduced radii, placed near stations.

On moderate inclines the speed is greater during the descent than during the ascent, to allow therefore for this difference it would be better to give a greater amount of cant to the descending than to the ascending line; but this difference ought to vary with the incline and with the position of the

curve relatively to the stations; hence arises a complication, which scarcely permits of the introduction as a general rule of an unequal amount of cant upon the two lines in curves on inclines. On the Eastern of France system it is applied only at those points, where the inequality in the speeds is constant and notable.

On the railway of the Palatinate the following values have been adopted for the extra width of gauge, and for the elevation of the outer rail.

RADIUS.	EXTRA WIDTH.	CANT.	
Chains.	Inch.	Inch.	
100	0	$\frac{5}{8}$	Normal gauge in straights $4'\cdot 8\frac{1}{2}''$
75	0	$\frac{7}{8}$	
60	0	1	
50	$\frac{1}{8}$	$1\frac{1}{8}$	
45	$\frac{3}{16}$	$1\frac{1}{4}$	
40	$\frac{1}{4}$	$1\frac{1}{2}$	
35	$\frac{5}{16}$	$1\frac{3}{4}$	
30	$\frac{3}{8}$	2	
25	$\frac{1}{2}$	$2\frac{1}{2}$	
20	$\frac{9}{16}$	$3\frac{1}{8}$	

On the State Railways in Bavaria the extra width only commences with curves of a radius less than 43 chains; its amount is,

RADIUS.	EXTRA WIDTH.	
Chains.	Inch.	
Up to 36	$\frac{1}{8}$	Gauge in straights $4'\cdot 8\frac{5}{8}''$
From 36 to 29	$\frac{1}{4}$	
From 23 $\frac{1}{2}$ to 22	$\frac{3}{8}$	
From 20 to 19	$\frac{1}{2}$	
For 16 $\frac{1}{2}$	$\frac{5}{8}$	Cant $4\frac{5}{8}''$
For 16	$\frac{3}{4}$	
For 14 $\frac{1}{2}$	$\frac{7}{8}$	

In the principal stations an extra width of $\frac{7}{8}''$ is allowed, except on the main lines.

On the Steïerdorf line (Banat) the normal gauge, $4' 8\frac{1}{2}''$, is increased in curves to $4' 9\frac{3}{4}''$; this additional $1\frac{1}{4}''$ is quite insufficient for the curves of $5\frac{1}{2}$ chains radius, which are very numerous upon this line; the breadth however of the tyres of the wheels does not allow of any further increase.

The Dresden meeting (1865), while admitting that the minimum radius of the curves, fixed as far as possible at 15 chains even for mountain railways, may exceptionally be reduced to 9 chains, named however 1″ as the absolute maximum for the extra width (*).

It also advises, that the ordinary gauge be preserved so long as the radius is under 30 chains.

The first injunction, results from the necessity of assuring, not only without danger of running off the rails, but also while retaining a sufficient bearing of the wheels upon the rails, the circulation of the rolling stock on the different lines, the dimensions of which are not the same. But, assuming the most unfavourable limits allowed by the "Vereinbarungen" it can be seen, that the amount of play might be increased still further in very sharp curves.

Article 113 fixes for the amount of play in straights, $\frac{3}{8}''$ for the minimum and 1″ for the maximum; this last figure corresponds to the greatest allowable wear of the flanges

Besides we have (Pl. VIII, fig. 10),

AB =	4′ $8\frac{1}{2}''$	in straights	(art. 6)
CD =	4′ $5\frac{3}{8}''$	at least	(art. 114)
DE =	5″	at least	(art. 115)

for a pair of wheels, with the maximum of wear, and having one of the flanges, b, applied against the rail, the limit of play is 1″ in straights;

x being therefore the maximum thickness of the worn flange,

$$CH = 4'\ 5\tfrac{3}{8}'' + x + 1''; \quad \text{and } CH = 4'\ 8\tfrac{1}{2}'' - x; \quad \text{therefore } x = 1\tfrac{1}{16}'';$$
$$\text{and } EH = 5'' - (1\tfrac{1}{16}'' + 1'') = 2\tfrac{15}{16}''.$$

With the additional width of 1″ in curves, the bearing of the tyre upon the rail would then still be 2″; it might without inconvenience be reduced by $\frac{3}{8}''$.

On the northern of France the extra width is, the gauge in straights being 4′ $8\frac{7}{8}''$, 0 up to 20 chains; $\frac{3}{8}''$ from 20 to 10 chains; and $\frac{3}{4}''$ from 10 to 5 chains radius.

The breadth between the wheels, with the normal gauge of 4′ $8\frac{7}{8}''$ gives a play of 1″ for the axles of the carriages, and of $1\frac{1}{8}''$ for those of the locomotives. To preserve the normal gauge upto curves of 20 chains radius appears hardly to be warranted, especially for a line upon which the speed is considerable, and where they endeavour, with good reason, to place as far apart as possible the extreme axles of the rolling stock.

(*) "Vereinbarungen," etc., art. 17.

On the Paris and the Mediterranean, and on the Western of France they have gone even further. Upon the former the extra width also only commences with 20 chain curves; it is likewise 1″, but it does not increase for the smaller radii. Upon the latter the gauge template is always 4′ 9″, in curves as well as in straights, no matter what the radius is.

Upon the Northern of France the amount of cant is

RADIUS.	CANT.	SPEED.
Chains.	Inches.	Miles.
Up to 100	$1\frac{1}{2}$	50
— 75	2	50
— 60	$2\frac{1}{2}$	50
— 50	3	50
— 45	$3\frac{1}{4}$	50
— 40	$3\frac{1}{4}$	46
— 35	$2\frac{1}{4}$	37
— 30*	$2\frac{7}{8}$	37
— 25	$2\frac{1}{4}$	31
— 20	$2\frac{7}{8}$	31
— 15	$3\frac{7}{8}$	31

The influence of excess of cant upon slow trains has been shown on the incline from Chantilly to Creil (Northern of France). As has been already stated (106), the rails of the descending line, which had not been fixed to the sleepers, travelled in the same direction as the trains. In the curves, the rate of progression was not the same for each line of rail; it being found, and not without surprise, that it was greater on the inside rail; had this inequality been reversed it would have seemed natural, as it is the outer rail which by its successive impulsions to the wheel-flanges, gives to the carriages their centripetal deviation. This apparent anomaly is explained by the action of the slow trains, and by that of the fast trains; which slacken their speed at the approaches to stations.

On the Western of France the elevation is,

Radius. . .	150 chains.	100 chains.	75 chains.	50 chains.	30 chains.	20 chains.	15 chains.	$12\frac{1}{2}$ chains.
Cant. . . .	$\frac{5}{8}$″	$1\frac{1}{4}$″	$1\frac{5}{8}$″	$2\frac{1}{2}$″	3″	4″	$4\frac{3}{8}$″	$5\frac{1}{8}$″

On the Paris and the Mediterranean line, an order dated April 1st 1863 fixed the cant as in the following table.

RADIUS.	CANT	
	speed 31 miles.	speed 25 miles.
Chains.	Inches.	Inches.
100	1	$\frac{3}{4}$
75	$1\frac{1}{4}$	1
50	2	$1\frac{1}{2}$
30	$3\frac{1}{4}$	$2\frac{3}{4}$
20	5	4
$17\frac{1}{2}$	$5\frac{3}{4}$	$4\frac{1}{2}$

But a subsequent order, 23 October 1864, augmented it.

" Experience has shown," it says, " that an amount of elevation calculated only in proportion to the centrifugal force is not sufficient. Thus on the section of the line between Blaisy and Dijon a very intelligent platelayer found it necessary to give $2\frac{3}{4}''$ of cant on curves of 50 chains radius, which corresponded to a speed of 48 miles per hour; the actual one for the trains was not above 38 miles, or about $18\frac{4}{7}$ yards per second; the amount of cant corresponding to the centrifugal force due to this rate being but $1\frac{3}{4}''$. It had been noticed, that the locomotive while passing over the curves caused a clear grinding noise, whenever the amount of cant was not sufficient, and that $2\frac{3}{8}''$ of elevation scarcely caused it to cease. Hence we have concluded, that under these conditions the cant ought not to be less than,

$$\frac{2\frac{3}{8}'' \times 1000}{R} = \frac{66}{R},$$

" but now that the speed of the trains on the main line is augmented, we imagine that on this line the formula $\frac{77}{R}$ is not too considerable.

" Again on the portion between Clermont-Ferrand and Brioude, where the curves are sharp, an elevation of $5\frac{1}{8}''$ (corresponding to a speed of 36 miles) has been given to the outer rail in curves of 15 chains radius; where the actual speed ought not to exceed 25 miles an hour, requiring but $2\frac{3}{8}''$ of cant to counteract the centrifugal force due to this rate. Another proof, that the necessity for the cant does not arise only from the centrifugal force, is that in the sharp curves at the stations, trains going slowly nevertheless sometimes got off the line; and that when the provisiona- line was laid at Terrenoire near Saint-Etienne (Loire), locomotives travelling slowly got off on the curves of $11\frac{1}{2}$ chains, when the cant was less than $5\frac{1}{2}''$.

" Also in the sharp curves at the main stations notwithstanding the cant, the inner side of the concave rail presents a polished appearance, arising from the fact that this rail is constantly being ground by the wheels of the locomotives, which on account of the rigidity of their frame have a tendency to mount upon it."

The whole railway was consequently divided into four classes :

1st Lines with curves of considerable radius, and travelled over at very great speed; the formula for the cant being $\frac{77}{R}$;

2nd Lines with curves of easy radius, and a fast rate; $\frac{66}{R}$;

3rd Lines with curves of moderate radius, and mean speed; $\frac{55}{R}$;

4th Lines with sharp radii curves, and slow travelling; $\frac{44}{R}$.

These values can be reduced by one half at those stations, where all the fast trains, even the special ones, stop or slacken speed. On the contrary it is recommended, that these values be somewhat increased on those inclines, where there may be reason to fear that the rate fixed for the fast trains, is sensibly exceeded.

201. If an excess of the elevation of the outer rail can diminish the tendency of the carriages, and especially of the engines, to run off the rails on the outside of the curves, on account of the rigidity of their frames, this result is certainly of too much importance to be neglected merely on account of a few inconveniences. But it would be interesting to ascertain whether the facts observed on the Mediterranean line point really to an excess in the elevation, or whether they are not owing to its being simply put in harmony with exaggerations in speed which are frequent enough.

For example, between Blaisy and Dijon there is an incline of 1 in 125; and it is well known that engine drivers have a tendency to increase in similar cases the rate of travelling, to make up for any loss of time, which they can thus do in part without an additional consumption of fuel.

The grinding noise, mentioned in the preceeding order, would be less perceptible if the play of the line had been increased; and perhaps it would be better to have recourse to this means, combined with the ordinary amount of elevation, already more than sufficient to counterbalance the centrifugal force, than to exaggerate this latter.

A certain amount of excess upon the theoretical elevation may however be justified on inclines. For, though with one carriage only the centrifugal force tends merely to press it outwards off the line, or to urge the flanges of its outside wheels against the rail, yet with several carriages joined together in a train it is no longer so, when the engine driver in order to slacken speed, puts on the break of the tender, or if necessary reverses the engine; in fact commences to make use of it very effectively to check the movement from the front of the

train. The buffers are then pressed one against the other, and in consequence of the curvature of the system inscribed within the curve, the inside buffers of any carriage are driven in more than its outer ones; the direction of the pressures, to which they are respectively subjected at each end, forms with the axis of the carriage an angle greater in proportion as the carriage is longer, and the radius of the curve smaller; the resultant therefore of the pressures upon the buffers is directed towards the exterior of the curve, and is so much the greater, all things else being equal, the more considerable the pressure exercised upon the carriage is; viz., the nearer it is to the head of the train.

202. The amount of cant in curves on embankments is moreover to be added to that elevation, which during the first laying is given to the outside rails of both lines, to compensate for the settlement, which shows itself generally at the edges of the earthwork; this precautionary elevation is commonly $\frac{3}{4}$".

203. *Distribution of the cant with circular connecting curves.*— The application of the cant in practice presents in its detail a difficulty, which arises from the nature of the curves exclusively used up to the present time on railways.

Whilst on ordinary roads the connecting curves between the straights are almost always parabolic, circular ones have always prevailed until now upon railways. In fact, once the angle between the straights, and the tangent points are given, it is advisable to select as flat a curve as possible; and the radius of a circular arc is greater than the minimum radius of the curve composed of different radii would be. But on the other hand in passing directly from a straight to an arc of small radius the carriages feel a sudden deviation. Moreover the full elevation cannot be given all at once, either it must commence before the origin of the curve, that is to say too soon, or start gradually from the tangent point itself, and then let it reach its full value too late. It is generally the former method which is adopted.

On the "Gebirg's Bahn," for example, the instructions to the platelayers are to approach the proper amount of elevation by an incline, placed upon the tangent. The same course is followed on the Eastern of France. If the straight between two contrary curves is too short, or (which aught to be avoided as much as possible) if these two curves run immediately into one another, the elevation is made null in the middle of the tangent, or the common origin of the two curves, and from that point the two outside rails are raised gradually.

On the Western of France the cant also exists throughout the whole extent of the curve; on a single line, run over in both directions, it is approached by an incline at each end situate upon the tangent, but on a double

line a different method is followed, the inclined plane is placed upon the tangent at the entrance to the curve, and upon the curve itself at its exit; the elevation is also a little forced on the outside line.

The inclination ought to be sufficiently easy not to cause any perceptible alteration in the distribution of the weights of the carriages, of the locomotives especially, while their wheels are resting, the one pair on the incline, and the other on the horizontal rail. This incline is 1 in 1000 on the "Gebirg's Bahn," the Eastern and the Western of France; upon the Paris and Mediterranean line it reaches 1 in 500, and even 1 in 333.

204. *Distribution of the elevation over a connecting curve.* — The necessity for distributing the elevation over an easy incline naturally leads to the idea of also dividing gradually the curvature itself, in such a way as to establish at each point, between the cant and the radius, the relation that ought to exist between these elements for a given speed. This question, being part of the first formation of the line, hardly comes within the limits of this work; but as, on the other hand, it is connected with an important detail of the permanent way itself, it is necessary to say a few words about it.

If ρ is the radius of the circular arc adopted to connect the two straights including the angle α, then $t=\rho \cot \frac{1}{2}\alpha$ represents the length of the tangents, and $S=\frac{eV^2}{g\rho}$ the corresponding elevation; and $\frac{1}{i}$ being the inclination of the slope upon which it is to be distributed, then the developed length L of the curve, to be inserted between each straight and the arc of the radius ρ, will be $L = iS$.

The circular arc ought upon this length to be replaced by a curve of which the radius, decreasing, commencing at the straight, from infinity to ρ, should have at each point the value which corresponds to the difference of level between the two rails at the same point.

The axes being the tangent and the normal, the origin itself of the curve, and s and r, the elevation and the radius at the point where the abscissa is x; we have

$$s=\frac{eV^2}{gr};\ \text{and}\ \frac{1}{i}=\frac{s}{x};\ \text{whence}\ \frac{gx}{eiV^2}=\frac{1}{r}=\frac{\frac{d^2y}{dx^2}}{\left(1+\frac{dy^2}{dx^2}\right)^{\frac{3}{2}}}.$$

If the curve with the varying radius is supposed to diverge so little from

the straight that, throughout its whole extent $\frac{dy^2}{dx^2}$ may be neglected before 1, the proceeding equation reduces itself to

$$\frac{d^2y}{dx^2}=\frac{gx}{eiV^2};\quad \text{whence } y=\frac{gx^3}{6eiV^2};$$

the equation of a curve, analogous to that of a prism fixed at one end, and acted upon at the other by a weight; the flexion being so slight, as in the preceding, $\frac{dy^2}{dx^2}$ may be neglected, before 1.

Such is the reason why this varying curve has been pointed out by Mr J. Weisbach, and others in Germany (*), as the one which it is convenient to insert between the straight and the circular arc, in order to distribute the elevation.

The same remark has since been made by Mr Chavès, engineer on the Northern of France (**), who besides was certainly unacquainted with Mr Weisbach's work.

The hypothesis of a very slight deviation between the straight line and the connecting curve is not always admissible; it may even be got rid of, without complicating the solution, by forming this curve of a series of circular arcs, tangent to each other, of the same finite length l, and in number $n=\frac{L}{l}$. The n successively decreasing radii $R, R_1, R_2 \ldots R_{n-1}$ (PL. VIII, fig. 4) are obtained as follows.

The element l being but small, the length of one rail, for example, there may be substituted for the variable height of these points a constant one, that of its centre; we then have:

For the first radius R, commencing with the straight, the mean relative height of the element l is

$$\frac{l}{2i}=\frac{eV^2}{gR};\quad \text{whence } R=\frac{2eiV^2}{gl}=\frac{2Si\rho}{l};$$

for the second radius R_1, the mean height of the element l is

$$\frac{2}{3}\frac{l}{i}=\frac{eV^2}{gR_1};\quad \text{whence } R_1=\frac{2S}{3}\frac{i\rho}{l};$$

(*) "Der Ingenieur" by Mr J. Weisbach, page 816 (Vieweg and Son, Brunswick, 1863).

(**) "On the rational connection of curves and straights" (Mémoires de la Société des Ingénieurs Civils, 1865, part. 3, page 339).

for the third radius R_2, the mean height is

$$\frac{5}{2}\frac{l}{i}=\frac{eV^2}{gR^2};\ \text{whence}\ R^2=\frac{5}{2}\frac{Si\rho}{l}$$

. . . .

for the n^{th} radius, R_{n-1}, the mean height is

$$\frac{2n-1}{2}\frac{l}{i}=\frac{eV^2}{gR_{n-1}};\ \text{whence}\ R_{n-1}=\frac{2n-1}{2}\frac{Si\rho}{l}.$$

For the $(n+1)^{th}$ radius, R_n (the first element l described of the radius ρ, and which is consequently horizontal),

$$\frac{2n-1}{2}\frac{l}{i}+\frac{1}{2}\frac{l}{i}=\frac{nl}{i}=S=\frac{eV^2}{gr^u};\ \text{whence}\ R_n=\frac{eV^2}{gS}=\rho,$$

as it ought to be.

But the arc of the radius ρ, thus arrived at, has its centre no longer on the bisectrix of the angle formed by the two straight lines; the two arcs, having their centres placed symmetrically on either side, cut one another, and it would require a little forcing to reestablish the continuity at the summit of the curve, which, besides this break, diverges more or less from the arc with constant radius extending from one straight to the other. The tangent point differs also from the origin of the circular connecting curve. This last consequence, common both to the varying curve and to that laid by finite circular arcs, would hardly matter for a line about to be constructed, where the manner of laying is not so rigorous; but when it is required to regulate in a more theoretical manner the cant on an already existing line, it is absolutely necessary that the deviations, relatively to the first laying, wholly by circular arcs, be very slight, and that a very small amount of forcing be required to correct the want in the continuity.

Mr Chavès has proved, that it is sufficient in practice simply to place the connecting curve end to end with the circular arc with the normal radius ρ. The connecting curves, calculated by him, and which the Northern of France has adopted, satisfy sufficiently the different conditions, and especially that of diverging but little from those parts of the tangent and of the circular arc, for which they are substituted, though, it is true, the distance is but short. We shall refer our readers for further information, which would carry us too far from our subject, to the pamphlet published by the author (*); but have our-

(*) "Mémoires de la Société des Ingénieurs Civils de Paris", 1865, part. 3, page 339.

selves meanwhile borrowed from it, the diagram of curves which accompanies the work (Pl. III, fig. 1), and the example which Mr Chavès has annexed to it, in order to make its use more fully understood.

" Suppose it be required to trace a curve of 50 chains radius: figure N° 8 tells us, " that the tangent point must be brought forward a length of 49′ 9″; commencing at " this point the rational curve is constructed by the aid of the abscissæ 19′ 18″, " 39′ 4″, 59′ 0″. . . . 118′ 0″ (19′ 8″ rails), and their corresponding ordinates, $\frac{1}{16}$″, $\frac{3}{8}$″, " 1 $\frac{1}{8}$″, ... 8 $\frac{3}{4}$″.

" The plan of the curve being thus constructed, there only remains to give the " sleepers the inclination required, in order that the rails may have between them " the relative elevations, which are indicated at the right of the curve; viz, $\frac{1}{2}$″ . 1″. . " . . 3″. Starting from this last point, of which the ordinate is 8 $\frac{3}{4}$″ the circular arc " commences with the same ordinate; the preceding portion, 69′ 3″ long, as well as " 48′ 9″ of the tangent, being replaced by the connecting curve.

" It is only necessary, as is usually the case, to lay with regularity the connection " of the two curves, which is not rigorously the common tangent at this point.

" Even if the beginning of the connecting curve does not hit upon a rail joint, and " this is most generally the case, the abscissæ, ordinates, and amounts of elevation " relative to the tangent point will still be used all the same."

For example, with a radius of 20 chains, and a speed of 30 miles the greatest divergence between the circular arc and the curve is 2 $\frac{1}{4}$″; the inclination distributing the elevation is rather more than 1 in 500, and the total length of the curve substituted on the tangent and the circular arc does not exceed 118 feet.

The elevation, or the difference of level of the two rails is obtained by a contrary inclination being given to the two parallel lines; elevating the outside rail, and depressing the inside one; so that the level of the centre line is not altered.

The cant, which corresponds to slow speeds, is very slight; it can therefore be suppressed at the principal stations, where all the trains stop, as well as in sidings.

205. *Connecting curves, and the horizontal deviation of the cariages.* — When, as on the Northern of France, it is only a question of the elevation, the curve which connects the two straights is modified only towards its extremities, it remains circular throughout the whole of the rest. One detail in laying the line is improved without sensibly affecting its setting out; in fact upon lines with curves of large radius, such as the one in question, there is no necessity to tone down the horizontal deviation of the carriages by dividing it. But upon lines with sharp curves the case is different; it is here necessary to replace the

circular arc, often over a considerable portion of its length, by a species of multiradial curve, throughout the length of which the difference in level and in deviation are distributed simultaneously : it is then however the second result, which is the main consideration, and which regulates the laying of the line. Such is the case upon the Brenner line, from Verona to Innsprück; the engineer in chief, Mr Thömen, determined to form by a series of decreasing radii the approaches to the numerous 15 chain curves upon this fine passage through the Tyrolean Alps.

208. *Difference in the lengths of the outside and inside arcs.* — The corresponding joints of the two lines of rail, as well as the sleeper upon which they hit, ought to be placed exactly at right angles to the axis of the line. In the curves, to fulfil this condition, it is necessary to make up the difference of the two arcs, inside and out, and consequently to place rails of a reduced length upon the former. It is however important to use one length suited to the different radii usually in use, to simplify the endeavour to make the rails fit, and to avoid errors in using it.

With the standard rail at 19'.8", the short rail is reduced to 19'.6". The distribution of this rail, for the several radii is upon the Western of France regulated by the following table.

RADIUS. 1	LENGTH on the inner arc corresponding to 19'.8" on the outer one. 2	DIFFERENCE between 19'.8" on the outer arc, and the corresponding length on the inner arc. 3	NUMBER of 19'.8" rails on the outside to one 19'.6" rail on the inside. 4	WHOLE NUMBERS to regulate use of 19'.6" rail. 19'.8" rails on the outside. 5	19'.6" rails on the inside. 6
chains.	feet inches.	inches.			
12 $\frac{1}{2}$	19 6 $\frac{5}{16}$	1 $\frac{11}{16}$	1·114	11	10
15	19 6 $\frac{5}{8}$	1 $\frac{3}{8}$	1·333	13	10
17 $\frac{1}{2}$	19 6 $\frac{7}{8}$	1 $\frac{1}{8}$	1·556	31	20
20	19 7	1	1·778	9	5
25	19 7 $\frac{3}{16}$	$\frac{13}{16}$	2·222	11	5
30	19 7 $\frac{5}{16}$	$\frac{11}{16}$	2·667	27	10
35	19 7 $\frac{7}{16}$	$\frac{9}{16}$	3·101	31	10
40	19 7 $\frac{15}{32}$	$\frac{17}{32}$	3·200	16	5
50	19 7 $\frac{5}{8}$	$\frac{3}{8}$	4.444	22	5
55	19 7 $\frac{11}{16}$	$\frac{5}{16}$	4·969	5	1
60	19 7 $\frac{23}{32}$	$\frac{9}{32}$	5·333	53	10
65	19 7 $\frac{3}{4}$	$\frac{1}{4}$	5·780	29	5
70	19 7 $\frac{25}{32}$	$\frac{7}{32}$	6·220	31	5
75	19 7 $\frac{13}{16}$	$\frac{9}{16}$	6·667	67	10
90	19 7 $\frac{27}{32}$	$\frac{5}{32}$	8·000	8	1
100	19 7 $\frac{7}{8}$	$\frac{1}{8}$	8·889	89	10
125	19 7 $\frac{29}{32}$	$\frac{3}{32}$	11·111	111	10
150	19 7 $\frac{15}{16}$	$\frac{1}{16}$	13·333	133	10

Take for instance, a curve of 50 chains radius.

According to column 4, it requires, for each length of 4.444 rails (of 19'8"), on the outside, one 19'.6" rail on the inside. At first on the shorter arc is placed one short rail to four long ones; and as the difference in the lengths is thus a little exaggerated, one in five is used where required, so as to lay with as much regularity as possible five short rails to each twenty two of the long ones, as is shown in colums 5 and 6.

It is only, one may suppose, in very particular cases that the length of the curve will require the rigorous application of this rule. When this is not so, a 19'.6" rail can be laid upon the tangent, in order to regain the final difference in the lengths by dividing it over a number of rails sufficiently great to avoid too wide joints.

The rule for the distribution of the short rails is sometimes rather less exact, but it is at least easy of enunciation, if not simpler in application. On a part of the Paris and Mediterranean line for instance, the rule is as follows; " On the " inside of curves a 19'.6" rail must be used instead of a 19'.8" one, whenever

"the end of the preceding rail projects $\frac{3}{4}''$ beyond a square set against, and passing through the extremity of the outside corresponding rail." For radii of 10 chains and under, rails shorter than 19'.6" are required; on the Northern 19'.4" rails are used with the former; this length is easily procured on the spot by taking 4" off the 19'.8" rails; as a fish-plate bolt hole is punched at this distance from the end, and therefore only needing a second hole to be punched 4" from the first one.

With such sharp curves it is better to give up making the joints of the inside and outside rails correspond with each other, and to cross-joint them. Figure 21, Pl. VII, shows the modification allowed in this case on the Northern in the spans, in order to give to every joint an equal solidity. This modification, as may be seen, amounts in fact to inserting one sleeper more, eight instead of seven for each length of rail.

§ II. — Tendency of the line to widen out in curves.

207. In straights, the flanges of the wheels do not press against the rails except accidentally, caused by imperfections in the permanent way, or in the rolling stock, by badly packed sleepers, inequality in the diameter between the two wheels on one axle, want of parallelism in the axles, obliquity in traction, etc. It is not so however in curves; for even if the speed is the one that corresponds to the cant given, and if the wheels when at rest have plenty of play between the rails, the flanges strike against them, in consequence of the parallelism, or of the insufficient convergence of the axles, and of the connexion of the carriages (201); these last pivot constantly round a vertical axis, under the pressure caused by the outside rail on the front wheel, and by the inside rail on the hind wheel; the reaction of the flanges also tending to widen out the gauge by the transverse slipping of the rails. This must be combated, either by making the outside fastenings more solid, or by connecting them with the inside ones.

In certain cases it has been thought necessary to take precautions against the displacement of the sleepers themselves. Thus on some of the German lines stakes have been driven in at the ends; sometimes these are placed only on the outside of the curve, merely preventing centrifugal movement, and at others, as on the "Gebirg's Bahn" they are applied at both ends; in some cases they are used especially to prevent the tendency of the rails, bent on the spot (210), to straighten themselves by their elasticity.

In the $5\frac{1}{2}$ chain curves on the Steïerdorf line another method was resorted

to; it was sought by means of the thrust of the ballast itself more completely to oppose the outward pressure of the flanges; and for this purpose, the three middle sleepers out of the seven supporting each rail, are bolted on to a longitudinal balk underneath, placed along the centre of the line, and which could not be displaced without forcing back the ballast along its whole length. These expedients may in some cases be necessary owing to the sharpness of the curves and the want of stability in the ballast, but in general they may be dispensed with. To prevent transverse displacement of the rails, it is almost always sufficient, as is found to be the case for longitudinal displacement, to connect them rigidly with their supports.

The advocates of the chair claim for it (31), that by means of its foot this connection between the two fastenings is effected; the advantage is but slight (37), and is only true up to a certain point. Once the rust has fastened upon the part of the spike passing through the chair, or upon the body of it in the wood, there is very little chance of the strains being at all evenly divided between the two spikes; to effect this the rate of destruction ought to be the same in each. Simple plates of wrought iron, for the reason that they are thinner, and that their holes dry more easily, are better fitted to realise the simultaneous action which is desired; they are also very often employed with the inverted ⊤ rail.

In curves of medium radius, up to about 20 chains, a single plate suffices, the joint being the natural point of application; with sharper curves one is often placed also in the middle, as on the Saarbrücke and Treves line, but if the radius is very small, they are used throughout, as is the case on the Semering, $9\frac{1}{2}$ chains, and on the Steïerdorf line, $5\frac{1}{2}$ chains; on the latter the joint plates, as well as the middle one, have also a projecting rib, which turns over the outside edge of the foot of the rail.

With the bed plates are generally used, either spikes or screws of a larger diameter than on the rest of the line, or a pair of fastenings on the outside of the rail; a special spike has been adopted on the Semering line, and two outside ones on the "Gebirg's Bahn", but only to the outer rail in curves of 28 chains and under. Similarly the spikes on the outside of the outer rail were subsequently doubled in the curves in the passage of the Vosges on the Eastern of France, where a tendency in the gauge to widen out had been noticed.

208. The double spike when applied, as on the "Gebirg's Bahn", even to curves which may be considered as of large radius, would be superfluous, were it not that a detail, peculiar to that line, had the effect of counteracting the action of the joint plate, exactly in these curves. While designing their line the engineers started with the principle, that absolute uniformity in the

constituting elements is an illusion; and that, instead of tending towards that rigorous precision of the system when laid down, which it ought to cause, this pretended uniformity actually hinders it; consequently they have systematically admitted among the elements a perceptible amount of play, leaving to the platelayer the care of fixing exactly their relative positions.

Thus, instead of clipping precisely the foot of the rail, the raised edges of the joint plate have a slight excess of width between them over the breadth of the foot; the bolts also have a certain play in the holes of the plates (Pl. V, fig. 28). The position of the plates does not therefore fix exactly the gauge of the line, and their edges, which the foot of the rail does not press against in straights, and in curves of large radius, either upon the inner or outer side, do not assist in resisting the thrust of the flanges; which at the joints is opposed therefore only by the friction developed by the tension of the bolts, and by the load. To the spikes of the intermediate sleepers is therefore left the duty of fixing the gauge of the line when first laid, and also of maintaining it afterwards; they consequently acted very wisely in doubling them.

This want of preciseness at the joints, consequent upon the double play just mentioned, allows, and which is doubtless of some consequence, the bolt holes to be pierced in the sleepers alike in straights, and in curves, within certain limits of radius; this play permits of an excess of width of $\frac{1}{2}''$, which is considered sufficient for curves up to $14\frac{1}{2}$ chains radius. The outside edge of the rail when this limit is attained presses against the plate, which itself rests on the body of the bolt; and then only is the normal, or at least the ordinary condition attained. With sharper curves, the holes should be pierced with a special template, so as to augment the extra width between the rails to the limit, fixed, as is always the case, by the width of the tyres.

This arrangement accumulating so many pieces at the joint, and really paralyzing in great measure their action, is likely to have but few imitators. The use of bolts was moreover caused by the necessity of economy in the joint sleepers, which are costly; as spikes often split them. The holes are pierced the exact size so that the bolts may fill them completely, and not allow any water to get in.

209. Mr Desbrière has proposed, to resist the transverse slipping of the rail, a cast washer-nut 2″ in diameter let into the wood, and forming a collar to the screw or spike; each washer-ring has three little projections to enable it to retain its position (Pl. V, fig. 11). This expedient, which I first saw tried on the line from Algiers to Blidah, and since on the Northern of France, has given satisfactory results; it is a simple method of distributing over a greater sur-

face the horizontal pressure transmitted to the sleeper by the screw. The length inserted in the wood and consequently the resistance to extraction are reduced it is true; but, we have seen (59), that this need not be of any consequence. A half ring or simply a flat metal plate fixed in the wood, would serve the same end; it should however be circular in shape, as this greatly facilitates its being fixed; the hollow for it is made by means of a plate fixed at the proper height, either on the auger which pierces the preliminary holes (169), or on a special one having a guiding shaft which goes into the screw hole. The depth of this plate ought to be somewhat greater, than the thickness of that portion of the ring which comes under the rail; so that in making the circular hole, if the top of the plate be worked down to the level of the bottom of the notch in the sleeper, the upper surface of the ring when fixed will thus be a little below the underside of the rail, which ought never to rest upon it.

Some trials were made in the workshops at Algiers by means of a wheel-press to ascertain the influence of the ring upon the resistance of the spike to transverse strains.

Two sleeper ends, each having a spike sunk to the usual depth, were laid one on the other (Pl. VII, fig. 22), and kept together by the collar *c*, *c*, of the press without being in contact with them. The pressure, applied by the piston P upon the well levelled ends of the sleepers, was transmitted by the two spikes to the collar, by means of small iron blocks *t*, *t*, fixed under the heads, and representing the foot of the rail.

The spikes gave way simultaneously,

1^{st} Without rings, when the index gauge marked 8 atmospheres pressure;
2^{nd} With rings, when the index showed 17 atmospheres.

The addition of the rings therefore quite doubles the resistance; each experiment, made twice, gave exactly the same result.

Out of the four rings tried, three were broken after a displacement of $\frac{1}{16}''$ to $\frac{1}{8}''$; the fourth resisted by penetrating into the wood.

This experiment though sufficient for the comparison of the amount of resistance, can only give a summary and exaggerated estimate of their real value. The piston of the press being $8\frac{1}{2}''$ in diameter, the force applied was $3^{tons}\ 1\frac{1}{2}^{cwt}$ in the first case, and $6^{tons}\ 11^{cwt}$ in the second; each spike resisted therefore $1^{ton}\ 10\frac{3}{4}^{cwt}$ without rings, and $3^{tons}\ 5\frac{1}{2}^{cwt}$ with them, less the passive resistance.

Though only of use in curves with hard wood sleepers, the rings may be applied with advantage on straights with soft woods. In all cases it is only to the outside fastenings of the rail, that they are added; whether at the joint only, or also at one or even two intermediate sleepers.

On the Northern of France they are used only with timber other than oak and beech; up to 75 chains they are placed at the joint and at one intermediate sleeper, with curves of lesser radius at the joint and at two intermediates.

Many engineers prefer either bed plates, or double fastenings outside. Doubtless transverse displacement of the rail may be opposed by other means, but that which Mr Desbrière has pointed out is a good one, if it is not even the best.

§ III. — Curving rails in the yard.

210. The curvature of a rail of ordinary length, 18 feet, may be neglected in curves of a medium radius. Generally however rails are but seldom curved before being laid; so that in reality, excepting the slight and but little regular curving which the platelayers can give the rails, by forcing them when they are laid, or later on to cause any bends to disappear, the result is more a polygon than a curve.

The custom of bending the rails beforehand, though but little followed in France so far, except in particular cases, such as guard rails for crossings, etc., is on the contrary very common in Germany. On the "Gebirg's Bahn" for example, for curves up to 38 chains radius they merely work the sleepers longitudinally under the rails after they are laid, and then keep them in their place by stakes driven outside them (207); but with sharper curves, as these stakes give way and the line gets out of order, the rails are therefore previously bent.

The machine the most used in Germany is that of Mr Köhler, an engineer on the Saxony and Silesia railway. It is simpler than those with screws and cylinders, not costly, easy to work and to carry about. As shown in figs. 14 to 20, Pl. VII, the rail is placed on two supports *t*, *t*, and by means of two levers L, L, with straps, *e*, *e*, the projecting ends are bent down a certain distance, such as to give the rail when free the permanent curvature, corresponding to its length and the radius of the curve. The small blocks *t*, *t*, are about $\frac{3}{5}$ths of the length of the rail apart. By means of screws *v*, *v*, the position of the stop-plates, *a*, *a*, may be fixed at the known depth below the level of the supports, which is equal to the amount of curvature, the rail when loaded ought to have in order afterwards to retain its proper quantity.

Some previous experiments ought to have ascertained the ratio between these wo amounts, which is itself variable even in the same delivery of rails; so that some may be too much bent and others too little. This may easily be provided for by repassing them through the press; the ones inverted so as to di-

minish their curvature, the others in their original position. The levers L, L, as well as the small blocks t, t, can be fixed in the position, corresponding to the various lengths of the rail, as for each length there is a fixed frame to which the levers are fastened by the bolts b, b.

The rail between the supports t, t, being acted upon by a couple, then assumes a circular form under the force. This is afterwards preserved when free, as the elasticity has augmented in an equal manner the radius of curvature throughout the whole section. But the parts towards the extremities of the length, l, assume under the force P not a circular shape, but that due to the bending, of which the equation is,

$$y = \frac{P}{EI}\left(\frac{lx^2}{2} - \frac{x^3}{6}\right),$$

and in which the radius of curvature increases from the support t, where its value is $\frac{EI}{Pl}$, to the free end where it is infinite.

This defect is however of no inconvenience in practice; for there would be no real advantage in reducing the length of the parts affected by it, and which in fact would require the application of a much more considerable strain.

211. Endeavours have been made in one machine to combine bending the rail, and punching in it the bolt-holes for the fish plates; as there would be a certain advantage in performing with the same apparatus both the operations which are necessary in laying curves. The hydraulic punching machine described farther on (213) was designed with this object, but it has never had any application. To unite the two duties in one machine would be to increase its weight considerably, an inconvenience for a portable apparatus where lightness is to be desired.

212. *Bending by fall.* — The curvature of rails is sometimes performed without having recourse to any machine. The process consists simply in letting the rail fall sideways upon two supports, from a height proportional to the curvature: it is an ingenious application of the inertia of falling bodies. The velocity of the points which come in contact with the supports is suddenly destroyed; the force of inertia, acting on the rest of the solid and overcoming its elasticity, causes it to assume a permanent deformation. One can understand that the curve obtained is by simple bending, and that the unsupported extremities will raise themselves; although the force of inertia tends to keep them down, as is the case with the intermediate part. Whilst inertia

tends to lower the ends, cohesion seeks to raise them, in consequence of the concavity of the middle portion, and the latter influence overcomes the former when the supports are sufficiently wide apart; this distance as well as the height of the fall is determined by actual experiment.

The following, for example, is an order issued on this subject by Mr Ledru, engineer in chief of the Eastern of France to the members of his department.

" The resistance of the Vignoles rail to lateral deflection is a serious obstacle to lay-" ing with regularity curves of small radius, which are met with in crossings, or even " on the main lines of our new sections. It has long been considered necessary in Ger-" many in cases of this kind, to bend the rails before laying them down; but the " methods employed have until lately been costly and complicated, causing the in-" convenience of requiring a stock of special rails for laying in curves.

" Recently the desired object has been obtained by a very simple process, capable of " being applied on the spot at the time of laying, or of renewal; and which consists in " allowing the rail to fall sideways from a certain height on to two ordinary wooden " sleepers, placed about 18′ apart.

With height of fall of.	2′.2″	2′ 8″	3′.0″
Are obtained regular curves with a curvature of. .	$\frac{3}{16}$″	$\frac{3}{8}$″	$\frac{9}{16}$″
Corresponding to radii of.	45 chains.	30 chains.	15 chains.

" These numbers are not absolute; they may vary with the nature of the iron, but " they are constant for rails from the same foundry, and of the same time of manu-" facture. The workmen rapidly acquire the necessary experience to obtain with cer-" tainty the curvature, which is desired.

" I request you to have this method employed for any inverted ⊤ rail lines which " you may have to lay down.

24th June 1863.

§ IV. — Punching rails in the yard.

213. *Punching machine.* New rails are delivered, ready punched from the manufactories; but to apply fish plates to existing lines the railway companies have to do it themselves, and must use apparatus which are easy of transport. However to punch large quantities the machines should work quickly and cheaply, conditions which very portable ones can hardly fulfil. For operations on a large scale, preference should be given to those improved machines, powerful, and therefore cumbrous, which are erected at the workshops where the rails are brought to; these workshops, and consequently the apparatus, should be sufficiently numerous, so that the mean carriage of the rails be not

too considerable. The circulation of the trains, where there is a double line, does not suffer in consequence, as it is carried from one line on to the other.

On the northern section of the Paris and Mediterranean line, the preference is at present given to a punching machine similar to those which work in the foundries; it punches two holes at a time, and is worked by a moveable engine.

On the southern section, a hydraulic press punching machine, driven by hand, is used to fit on the fish plates. This machine, fixed on wheels, may be employed to punch the short pieces of rails, used to close up those sections, which have been laid simultaneously, or for filling in on curves (206). The results given by it have, it is true, been very moderate, but doubtless on account of its being badly made, for it appears to be well designed.

It may therefore be useful to describe, although as yet it has had no results, a fresh design, with only a few modifications in the details, for the application of the same principle (Pl. I, figs 8 to 11).

The rail R placed on a support, *c*, is backed up by the block V, which rests against the main cast-iron body piece T, connected by the bars *t*, *t*, to the body of the pump C; the sloping channel *o* receives, and passes away the refuse cut out by the two punchers *p*, *p;* the two injecting pumps, *ϖ*, *ϖ*, worked by means of the lever L, with its centre at, *a*, force behind the piston P the water they draw from the tank B, which forms the base of the machine, and rests on four wheels *r*, *r*.

A valve spindle *s*, worked by hand by means of the handle *m*, receives two positions corresponding one to the advance, the other to the return of the punchers. In the first (fig. 12) the valve shuts off the communication with the waste water pipe; the pressure of the water brought by the injection pipe, *i*, acts at the same time against the large piston P, and upon the small one P′ which is connected with the former by the cross bars θ, θ′, and the rods *l*, *l*. The area of the smaller piston reduces therefore the pressure on the punchers, but only in a slight degree; the larger piston being 10″ in diameter, and the other only 2″. As soon as the holes of the rail are punched, the valve bar receives its second position (fig. 8); intercepting the communication between the body of the pump and the return of the water, while the smaller piston is left free to he injection pipe *i;* as the pumps then only act upon the smaller piston, the larger one returns to its starting point.

214. *The Knee-lever.* — For the occasional use referred to it matters but little that the operation itself be somewhat longer or a little dearer, the essential condition is that the apparatus be really portable. With this object a smal

machine made by Mr Chouanaud has been tried on the Paris and Mediterranean line, formed by the combination of the knee-lever and of the screw (Pl. I, fig. 13). The bent lever forms an isosceles triangle; the power being applied to each one of the two arms by a screw v, acted upon by means of a fly wheel.

If P is the force applied to the circumference of the wheel of the radius l, Q the pressure on the puncher, h the thread of the screw, t its tension, d the distance AM, f the leverage, we have for the equilibrium of the bent lever aob (fig. 14),

$$Q = t\frac{d-f}{f},$$

and for the equilibrium of the screw, $t = P\frac{2\pi l}{h}$;

whence $Q = P\frac{2\pi l(d-f)}{hf}$

The relation would be the same for a handle acting by means of a screw on a simple lever t, oscillating round the fixed point o (fig. 14), but the ratio $\frac{Q}{P}$ would then be constant, whilst, and this is the special property of the knee-lever, this ratio increases rapidly, f diminishing, and d increasing slightly in proportion as ab approaches the perpendicular to a Q. The power of the machine therefore goes on increasing; it is equivalent to the combination of a screw with a lever of the first kind, in which the fulcrum approaches indefinitely the point of application of the resistance.

The objections made to it are,

1st The difficulty of separating the puncher from the rail after punching.

2nd The breakage of the steel round the joint pins.

3rd Its slowness, hardly punching 40 rails per day.

The first imperfection appears easy to do away with; the same may be said of the second, it is merely a matter of construction, and not inherent to the principle of the machine; whilst as to the third it is nothing very serious, the essential requirement of the apparatus not being to pierce quickly, but to be easy of transport.

Mr Chouanaud's machine is more expeditious, than those which give a circular movement to the drill; but a very considerable pressure is required to be exercised upon the puncher, and the combination of the two machines used, the bent lever, and the screw, is very adequate to produce this simply and

by means of a light apparatus. It would however be unnecessary to dwell any longer on machines, though interesting in themselves, but of which the importance is secondary. For accidental cases which may happen during the maintenance the foreman plate-layer makes use of the tools, more or less complete, which are at his disposal.

For fish plates with three bolts the two rails are placed end to end against one another, whatever kind of machine is used, and thus the two half holes are punched at once.

§ V. — Laying of the line on iron bridges without ballast.

215. The peculiarities in laying the line in this case are merely mentioned here for the sake of remembrance, as they are closely connected with the erection of the work of art itself. The only general fact to be noted here is the frequent use of longitudinal sleepers, which are useful in this case to prevent the consequences of a broken rail, and which hence ought to exclude the use of the chair rail.

On bridges of a small span, the joints of the rail are often done away with, and for this purpose some railway companies reserve to themselves in their contracts the power of ordering rails of an exceptional length up to 10 or 11 yards long.

§ VI. — Communication without transhipment between railways separated by a water channel, and where no bridge exists.

216. When a railway meeting a wide water channel is obliged to stop on its banks, because the erection of a bridge would be impracticable or too expensive, it becomes important to prevent the double transhipment of goods, and the accumulation of rolling stock remaining idle on either bank. The ordinary solution is to make use of a steam boat the deck of which, carrying one or more lines, is connected by means of platforms with those coming down to the banks, moveable either vertically or on an inclined plane; and thus having an up and down movement, the greater or less amount of which depends upon the variations in the level of the stream, or in a river near the sea upon the height of the tides. These works are generally expensive to establish and to keep up, but their very imperfections only show more clearly, the serious inconveniences of transhipment, and the importance of making some sacrifice to avoid it. Under this head especially we shall describe some instances of those works called in Germany " Traject-Anstalt " and in England

" Floating Railways ", though improperly so; and then examine a little more in detail a solution of the question recently applied on the Rhine, and which comes more directly within the scope of this work (223).

217. *Floating Railway " Traject Anstalt."* — These communications by means of steam vessels carrying the carriages and waggons, exist in Germany :

1st On the Elbe between Hohnstorf and Lauenburg;

2nd On the Rhine, between Ruhrort and Homberg; between Bingerbrücke and Rüdesheim; at Griethausen on the line from Cleves to Zevenaar, connecting the Rhenish and Dutch railway systems; and between Rheinhausen and Hochfeld on the Osterath and Essen line : the Rhenish Railway Co are constructing the line from Ehrenbreitstein to Beuel, which will have to be connected also in the same manner with the Beuel to Bonn Railway (*).

At all of them, except at Ruhrort and at Homberg, the means of communication between the fixed land lines and those laid on the deck of the boat is a platform (" Ubergang's-Wagen", " Ausgleichung's-Wagen ", " Anfahrtswagen "), rolling on an inclined plane, thus adapting itself to the differences of level, and made to receive several waggons at once on the rails, which are in continuation of those on the level.

Arrangements of this kind have been in use a long time in the United States; the oldest, I believe, on the Susquehannah, for the trains between Philadelphia and Baltimore, has been replaced recently by a fixed bridge. The luggage vans, and the sleeping cars of the passenger trains only were carried over. The river at this point is one mile across; its level varies very little, which greatly simplified the connection with the lines on its banks.

The same mode of communication is at work on the Connecticut, and on the Delaware at Philadelphia. It has just been installed on the Detroit river, the outlet of lake Huron into lake Erie, for the junction of the Great Western of Canada with the Central of Michigan; the gauge is different on these two lines, 5' 6" for the first, and 4' 11" for the second; a third rail has been added along the whole length, 88 miles, of the Great Western. The execution of these works rendered it necessary to do away with transhipment on the Detroit, which is half a mile wide.

The conditions here are somewhat more difficult than in the preceeding case, the lakes being subject to variations of level, sometimes sudden, amounting perhaps to four feet; the steamer has two lines, capable of receiving fourteen large eight-wheeled waggons.

(*) A fixed bridge, opened for traffic during the first months of 1867, has replaced the " Traject-Anstalt ", which existed between Ludwigshafen (Rhenish Bavaria) and Manheim (Baden).

In England, there occur some examples of a much more interesting character; one of them on the Tyne at North and South Shields, established thirty five years ago, appears to be of older date than any similar arrangements in the United States. But the most remarkable instance in the United Kingdom is found on the Firth of Forth in Scotland (*).

In figs. 1 to 6, Pl. XIV, is shown the method adopted at Granton, and at Burntisland.. The range of the variations of the Forth amounts to 16 feet; this is compensated for by the working of a horizontal platform of timber BC, rolling on an inclined plane of 1 in 6, connecting with the boat by means of a moveable platform or drawbridge AB, worked by hand over the jibs H, H, (figs. 1 to 3) by means of the windlasses T, T, fixed on the timber frame work BC; this weighs 70 tons and carries two lines, it runs on 24 iron wheels *r,r,r*, 2′ 6″ in diameter, having the flange in the centre of the broad tyre (fig. 3), and running in bridge rails inverted (figs. 2, 3, and 6). The drawbridge resting at one end on the platform, and at the other on the boat, ought without disconnecting to yield to the surging movements of the latter. This is the object of the universal joint (fig. 6), which forms the connection of each of the four beams of the drawbridge with the platform; the pin *t*, having at its centre a circular swelling, works in two blocks *p p*, of the same shape at the middle, but tapering off towards each end like a cone, and bolted on to the bearers of the platform *l*, *l*. This arrangement allows sufficient play to the end of the drawbridge in every direction; which can thus follow both the pitching and the rolling motion of the vessel, and yet allow the bearing beams to rest freely upon their supports. The counter weights ϖ ϖ (figs. 1 and 2), balancing the drawbridge, but not entirely, so that it may always rest on the deck, rise and fall with the vertical movement of the boat. Its horizontal displacements are provided for by the grooves *c,c,c,c*, (fig. 2), made in the deck, and in which run the ends of the bearers of the drawbridge. Articulated steel switches, fitting down on to the rails on the deck, complete the connexion; other switches placed at the back of the rolling platform connect with the land lines.

The inclination of 1 in 6, given to the approach slope, is considerable, but want of space did not allow of its reduction. This in any case could not have been effected without giving a great length to the drawbridge AB; it is at present 35 feet long, which is sufficient with the fall of 1 in 6, to prevent the boat being driven back upon the inclined plane, even with a very great swell.

The vessel is driven by a pair of engines each independent of the other; at first it had a rudder at each end, thus causing the plan of it on either side of

(*) See "Minutes of proceedings of the Institution of Civil Engineers", vol. XX, 1861, page 376.

its mid-section to be symmetrical, to prevent its turning broadside on; it was however found that a solid end stop with buffers was necessary to restrain the waggons, and the ordinary method was adopted. The deck carries three lines of way, capable of holding from 30 to 34 waggons, these are laid with bridge rails inverted, to prevent any projections on the deck. The movement of the platform is produced by an engine of 30 horse-power, the driving shaft of which *a* (figs. 4 and 5) carries three drums *b*, *b'*, *b''*, upon which are rolled the hempen cables to which the waggons are attached. The space between the two lines, being of the same width as they are, leads directly to the intermediate one M on the boat, in the same way that the two lines proper on the platform communicate with the two outside ones on the deck; hence the middle drum *b'*. By this arrangement there is the advantage of doing away with one, or rather two sets of points *l*, *l'*, and three crossings *m*, *m'*, *m''*; for, unless this had been done, the middle line M on the deck would have required to have been placed in communication with each of the two lines on the platform (fig. 15). It may be seen, that a pair of wheels coming from the side lines are still guided, while they pass over the junction I, J (fig. 2) of the hollows of the different rails, as the wheel, which is crossing these points is kept in place by its fellow; this direction is wanting it is true for those on the central line, but no inconvenience arises from it, as the tension of the rope prevents all deviation. Each of the three drums is furnished with a gearing apparatus, and with a band brake, which the engine driver works by means of a pedal.

The movement of the platform, much slower than that of the waggons, only $3\frac{1}{4}''$ per second, and which is moreover of less frequent occurrence, is imparted to it by the shaft R (figs. 4, and 5), carrying the toothed wheel S, itself receiving it from *a* by the spur gearing *r*, *r'*, ρ, ρ'. The drums *b*, *b'*, *b''*, never work at the same time as the wheel S, the pinion *r* is disconnected when one of the drums is in gear. During the passage of the waggons to and from the platform to the boat, the former is kept immoveable by two heavy iron stops LL (figs. 1 and 3), fitting between the teeth of the cast rack D D.

In ordinary weather the six miles between Granton and Burntisland are traversed in 36 minutes, loading and unloading take 8 minutes; the boat makes four or five double voyages in the 24 hours.

Passengers have to change, and are carried across in an ordinary steam boat.

Similar arrangements exist a little farther north, on the Tay at Tay Port and at Broughty Ferry, between these places the width of the river is only three quarters of a mile; the only essential difference consists in the slope of the inclines, only 1 in 8, on which the platforms move.

During 15 years these ferries have rendered indisputable service in facili-

tating the traffic between Edinburgh and the country north of the Tay; it is through them for instance, that the Fifeshire coals are able to compete in the Edinburgh market, from which up to that time they had been excluded.

But although these steam ferries constitute a great progress over absolute separation, necessitating a double transport, they are far inferior in value to a complete connection.

During bad or windy weather the passage of the Forth is difficult and tedious, many travellers going from Edinburgh to Perth or Dundee prefer to make a long round by Stirling. To avoid this the North British and the Edinburgh and Glasgow railways resolved to build a bridge between Blackness and Charleston, where the Forth narrows in perceptibly, and above which vessels of but slight tonnage pass to the various small ports. Mr Bouch's proposal for this great bridge, $2\frac{1}{4}$ miles long, included four lattice girder spans of 500 feet each. A fixed bridge was also projected over the Tay.

218. The Great Western Railway Company on its part, by its engineer in chief, Mr Fowler, brought forward a project for a bridge across the Severn at Old Aust, where the river is 2 miles wide, with about one third of it deep water.

Owing to the requirements of the navigation the platform was much raised above high water, and was carried on 10 spans of about 260 feet, and one of more than 600 feet, being above 130 feet more than the largest spans of the Britannia and the Saltash bridges (*).

Up to the present time communication between the railways on the two banks of the lower part of the Severn is only maintained by means of the ordinary navigation with transhipment, but which is practicable at any state of the tide. To render the landing stages effective for this purpose the Great Western, who had made the Bristol and South Wales Union line, have constructed on the left bank at New Passage a large open or pile pier with intermediate landing stage, so placed as to obtain a sufficient depth at low water during spring tides; on the right bank at Portskewett a very short pier sufficed, owing to the much greater inclination of the bank on this side.

219. The numerous arms of the sea which intersect the English coasts so deeply, and allow of large vessels penetrating far inland, have the inconvenience, slight it may relatively be termed, of placing obstacles in the way of a continuous railway system. The English are not the people to rest long content

(*) The London and North Western Railway have just finished a bridge, though less gigantic than the above, across the Mersey at Runcorn having three spans of 305 feet each. In this case there was no continuity to be established, but a mere reduction of 8 miles in the distance between London and Liverpool.

with an imperfect solution of a question, or to be deterred from projects, which may be in themselves gigantic, but the utility of which is well established; even this condition is not absolutely essential; with the spirit of competition, so eager, and so enterprising, which animates the English railway companies, it is especially when an attempt is made to deviate a traffic, which they consider as an attack on their rights, that the large companies make of their own accord very great sacrifices. It is probable, that in a few years in England railway trains will be seen crossing these broad inlets in its coasts, in the same way that on the continent those mountain ranges which at first appeared to oppose insurmountable obstacles, have been traversed (*).

220. The ferry on the Elbe at Hohnstorf and at Lauenburg (Pl. XIV, figs. 7 to 14), similar to those of the Forth and the Tay, was designed by Messrs Funk and Welkner, and erected at the common expense of the Hanoverian lines, the Berlin and Hamburg, and the Lübeck and Buchen; it has been at work since 1864.

The extreme variation of level is over 16 feet; the inclined plane upon which the rolling platform is placed has an inclination of 1 in 9; the drawbridge EF is 24 feet long. The platform carries only one line (figs. 9 and 10); and as its base of support must necessarily be much wider, it is supported, not as on the Forth by the rails V, V (figs. 1 to 3), upon which the waggons run, but by a wide special line MN (figs. 9, 10, 12, 13). It is united to the line on land by means of moveable switches 13′ 8″ long, and having towards the river an inclination of 1 in 30, to render less sudden the transit of the waggons, from a slope of 1 in 9 on the inclined plane, to the level on the platform.

In spite of the moderate incline of the approach, the six wheeled waggons do not accommodate themselves to this method, the rails form a broken line, so that in passing over the inflections of the incline O, P (fig. 7), a very great excess of weight is laid upon the springs of the end axles if the angle is inwards, as at the bottom of the incline, and on the springs of the middle axle if it is outwards, as at the top. The number of six wheeled carriages, belonging to the railways that are placed in communication by this ferry, is however but small.

Four wheeled waggons, easily adapt themselves to a greater incline, as that of 1 in 6 on the Forth. The difference of level between the buffers of two

(*) In corroboration of the above it may be stated, that a railway, of which Mr Brunlees is the engineer in chief, has lately (July 1869) been carried across the Solway Firth, at a point where it is nearly 1½ miles broad, on an iron viaduct 1950 yards long; consisting of lattice girders in 30 feet spans, supported on iron screw-pile piers, averaging 34 feet above the bed of the Firth.

consecutive waggons, placed each on a portion having a different incline, is of but little consequence. Whilst the eight wheeled waggons of the American type are much better suited to it, in spite of the great length of their frame, than are the six wheeled ones; as the end axles of the former are much closer to the buffers than with the latter.

As in Scotland the idea first entertained of doing away with any change for passengers has been given up; but here they are carried across in the same boat with the goods waggons. They embark and land by means of an open etty alongside of which the boat is placed, while at the same time the draw-bridge of the platform is made fast to its stern.

221. The ferry between Bingerbrücke and Rudesheim, connecting the "Rhine and Nahe" and the Nassau lines, is similar to the foregoing ones, but less considerable, and of a temporary nature. Passengers cross by steamboat, and the goods waggons in barges which can only carry three or four of them.

The same system was established in 1852, but in a temporary manner, at Ruhrort and Homberg; it afforded but little satisfaction however, not being equal to the wants of the traffic, which even at this period was very brisk; the rather frequent occurrence of accidents arising from the falling of waggons into the river brought mistrust upon the method of inclined planes, and it was decided to raise and lower the waggons vertically. The difference of level nearly 28 feet is overcome by means of a hoist. As the intermittent nature of the work, with a motive power acting directly on the load, would have necessitated the use of powerful engines working under conditions but little favourable to economy; the principle of storing up by means of an Armstrong accumulator, the power of an engine of less force, but working constantly was therefore adopted. A 30 horse power engine is placed both at Ruhrort and at Homberg.

The platform of the lift has two short lines 25 feet long, each receiving a four wheeled waggon, and between them a third line much longer, 36 feet, but which through want of space between them can only be used by itself; this is set apart for six wheeled waggons, and serves also to carry very long loads, of timber, etc., for which the single-line pontoons are used, which acted with the inclined planes. These last are still preserved, and work when the hoists are insufficient for the traffic.

The paddle steamer carries three lines like the platform, and can accommodate six four wheeled waggons on each of them; making twelve in all, as they are only on the two side lines. The boat, protected by buffers and guided by the jetties which narrow in towards the hoist tower, is brought up so that the ends of the rails on its deck come directly under those of the platform; it

is then firmly moored to the piles of the jetty, and the platform being lowered to the level of the deck, a large bolt connects the two firmly together.

A depth of 6′ 2″ at low water is maintained by dredging in the channel course followed between the two banks.

The two stations, erected however with unnecessary expense, especially in the masonry of the hoist towers, cost £37,000; to which must be added the price of the boat, nearly £12,000; the working expenses are also very great.

222. *Method adopted on the Rhenish Railways.*—The means employed by Rhenish railway companies on the Cleves to Zevenaar, and the Osterath to Essen lines differs in many ways from the preceding arrangements. The designer of them Mr Hartwich, followed the system, so successful for many years past in England in crossing arms of the sea, with ordinary carriages only it is true, but under very difficult circumstances. In principle it is only a steam barge guided by one cable and hauling itself on another. This system has been working at Devonport for more than thirty years, also at Southampton, and at Portsmouth. At Devonport the estuary, half a mile wide, with a variation in level of about 18 feet, is crossed by a boat with the engine in the middle with two lines on either side, and connects, by means of two hinged drawbridges at either end worked by the engine, with two inclined planes of 1 in 14 erected on the banks. It has been proposed to apply this mode of transport on the Mersey at Liverpool.

The regularity of service of these steam-ferries, interrupted only from time to time in case of very violent weather, determined Mr Hartwich to apply the same principle to the transport of trains; this he has effected with that ingenuity and practical sense which stamp all his works.

As at first projected movement was imparted to two barges, or, merely carrying pontoons, by means of cables from an engine on a barge moored exactly in the middle of the distance to be crossed. The two moveable boats working in opposite directions were to reach the two banks at the same time; it was found, that this arrangement did not suffice for the exigencies of the traffic, and independent pontoons, each carrying its own motive power, were then resorted to.

The steam barge P (Pl. XIV, figs. 16 to 20), carrying a single line, as does the carriage or landing waggon C C, works between two wire cables; the up-stream, which is the guiding one, is fixed, being moored every 40 yards to piles driven into the bottom of the stream, and is tightened at each end by a carriage frame with a counter weight descending into a well, and imparting to it a strain of 14 tons 15 cwt; the down stream cable, the hauling one, of a lesser sec-

tion, the strain upon it being only about 4^{tons}, passes over a fixed pulley and a loose one; the duty of the latter being to send the cable back to the former and to prevent its escape from the groove, which it would otherwise do, in consequence of the movement of the screw being parallel to the axis of the pulley. With the tension given to this cable a single turn of the fixed pulley is sufficient to prevent any slipping taking place.

The large pontoons carry ten goods waggons, or seven passenger carriages. The approach slopes, having an incline of 1 in 48, connect with the line on the pontoons by means of a rolling platform or landing waggon C C ("Anfahrts-wagen"), inclined 1 in 12 next the pontoon, and carrying a hinged projection *m n* inclined at 1 in 16 towards the shore; the end next the boat has articulated rail-ends, *ff*, which fit into funnel-shaped hollows *rr* made in the deck. Counter weights ϖ, ϖ (fig. 18), retain the switches *m n* raised, so that they caused no obstruction to the progress of the landing waggon when nearing the inclined plane. The former carries in front a projecting piece P, provided with two large friction rollers, ρ,ρ, which fits beneath the deck, the rollers sustaining and supporting between them a prow or spur, E, jutting out under the boat, the stern of which is thus made fast immoveably to the landing waggon; the junction is then completed by a kind of spring fastening, *vs* (fig. 18).

The connection is thus established, and its exactness is such, that passengers cross the river without leaving their seats.

As the motive power of the waggons is no longer a fixed engine but a locomotive, the slope of the approach inclines ought therefore to be limited; and on the other hand as the rolling platform, in consequence of this easy approach slope has a very great length of run, it was necessary to reduce its weight and also its dimensions; this explains the incline which it itself presents, and which the waggons have to ascend after having descended the inclined plane more than necessary; for a horizontal platform would have been much longer and heavier. The boat, decked, perfectly water tight, and insubmersible, has when fully loaded its deck but very little above the level of the water (fig. 19). The difference between the extreme levels being 25′ 6″, and the length of run of the carriage, with an incline of 1 in 48, is as much as 410 yards.

Both the boats and the landing carriage are built strong enough to carry locomotives; but the angle made by the rails at the junction of the inclined plane with the ascending slope of the waggon is too abrupt for engines with six wheels, the springs and end axles of which would be exposed to an excessive overweighing. These engines are therefore not carried over, but stop before reaching the above named point, the extra length of the landing carriage is compensated for by means of two specially constructed waggons V,V,

(fig. 20), remaining always attached to the engine; which by their aid at starting backs the train on to the boat, and on arrival with their assistance draws it away.

Haulage, which is so favourable to the utilization of the motive power, appears, in case of the passage of a river with a rapid current, striking the boats broadside on, to present a serious difficulty, in their liability to drift away; this has however been quite overcome by the way in which the guiding cable is moored.

The "Traject Anstalt" at Griethausen, on the Cleves line, has worked regularly since the early part of 1865.

The Rhenish Railway Company, feeling the urgent necessity of placing its system in communication with the mining and mineral country on the right bank of the Rhine, in the neighbourhood of Essen, had decided on the only natural and thorough solution, indicated by the importance of the interests to be served, that of a fixed bridge; but this idea, so wise as regards both the interest of the company and of the general traffic, was not considered to be so in a political point of view, and the company were obliged to be contented with half-measures. With the successful example of Griethausen before them they could have no hesitation in applying it also at Rheinhausen.

A complete examination of the ingenious details of the project, as designed and executed by Mr Hartwich, would be foreign to the object of this work; the subject of it however could neither be altogether omitted, nor could it be treated of at length. For full particulars we will therefore refer the reader to the description of it given by that celebrated engineer (*).

Judging by the rapidity with which fixed bridges have multiplied on the Rhine during the last few years there is reason to believe, that these "Traject Anstalt" will soon disappear altogether from this river. Undoubtedly the means of working these apparatus are simpler in certain cases in rivers themselves, than near their mouth, or upon real estuaries, as on the Forth; but the very variable state of the river, and the more severe climate of the valley of the Rhine, present at times special difficulties to the navigation. The application of these railway ferries appears on the contrary likely to be increased in cases where there is evidently no other means of avoiding transhipment.

The more the continental system developes competition between the railways the more will they recognize the necessity for unbroken transport to ensure them a share in the transit traffic. Thus there is now a proposal to

(*) "Erweiterungsbauten des Rheinischen Eisenbahn. Fahranstalten für den Eisenbahnverkehr." Berlin, 1867. Ernst and Korn.

establish some " Traject Anstalt " on the lake of Constance to connect the Bavarian and Wurtemburg lines with those of Switzerland.

§ VII. — **Bridge of boats between Maxau (Baden) and Maximiliansau (Bavaria).**

223. The connection of the Baden railways, near to Carlsruhe, with those of the Palatinate had become a necessity; the expense of a fixed bridge was too great, and on the other hand the idea of a " Traject-Anstalt " had been rejected not merely on account of the imperfection of the solution in general, but also in consequence of local conditions. The bed of the river being in fact irregular, and when the water was low it would have been impossible to maintain a sufficient depth from one bank to the other.

There remained therefore no choice but to establish a bridge of boats, which would impose no fresh obstruction to the navigation, moderately active, since a similar one for the ordinary carriage-road already existed at this point. The latter could not however be retained and another close to it be established for the railway; this would have been to double the hindrances in the way of the navigation, and which would have called forth very legitimate complaints from it. It was decided therefore to construct an entirely new bridge, carrying the railway and two roadways (Plates XV, and XVI).

This would not however entirely do away with the chances of interruptions in the service; for, if a steam ferry-boat would have been exposed to damage during times when the water was very low, similarly the bridge of boats on its part would be exposed to serious shocks from the ice, and occasionally during very severe winters necessitating its complete removal, when the boats would have to take refuge in the harbour of Maxau.

The works included (*),

1st The bridge proper, 256 yards long,

2nd The two approach slopes with a variable incline, 140 yards long in all.

The bridge is carried on 34 pontoons firmly connected in twos and in threes, and forming 12 spans solidly moored and tied together (Pl. XV, figs. 1 and 2). A special method of fastening allows of a passage being left for the navigation, three consecutive spans, two of them of 3 pontoons, and one of 2 only, being easily drawn aside and again set in place, form a passage more or less wide as required; the span of two pontoons being sufficient for the rafts of floating

(*) See the description of them entitled " Die neue Eisenbahnschiffbrücke Über den Rhein bei Maxau ", by Mr Becker, engineer in chief, and director of the Ponts et Chaussées; Carl Mäcken, Stuttgart, 1865.

timber. This arrangement was obliged to be adopted near to both banks on account of the changeability of the channel, which shifts gradually from one side to the other.

The variable load allowed for is,

1st On the railway, a train of five waggons, weighing 16 tons each, and a locomotive of 15 tons,

2nd On each roadway, a 3 ton cart;

In all 101 tons.

The maximum immersion of the pontoons, due to the variable load, was fixed at 8″; the train occupies a length of 46 yards.

If the load was only distributed over this distance, the corresponding surface, s, bearing upon the water would be

$$s = \frac{101^{\text{tons.}}}{8''} = \frac{3{,}626^{\text{c.f.}}}{\cdot 66'} = 5{,}494^{\text{s.f.}} = 610 \text{ square yards.}$$

But it is allowed, that, on account of the connection established between the different spans by the method of construction of the bridge, two thirds at most of the variable load would be borne by the pontoons immediately under it, the remaining third being distributed over the adjoining spans.

The pontoons (Pl. XV, figs. 3, 4, 8, 9 and 10) are 4′.7″ deep, 66′.0″ long, and 12′.2″ broad, giving 75 square yards of horizontal section; of these there are six, arranged in two spans, in the length of 46 yards, giving a total bearing surface of 450 square yards.

In the two spans adjoining the banks the three pontoons (figs. 3, 4, 5, 6, 7 and 8) are horizontally of more considerable dimensions 74′·0″ × 15′·2″ thus increasing their base to 108, instead of 75 square yards. The mean distance between them is besides less on account of their greater breadth, in fact the two first pontoons almost touch one another (figs 3 and 4); it being of importance to compensate, by the lesser immersion of these spans, for the want of rigidity in the connection of the line borne by them with that on shore.

If the same weight of about 100 tons is distributed over a greater length, with for example slightly laden or empty waggons, the total weight of the train may be actually greater without the limit of immersion, 8″, being exceeded; an additional advantage compared with moveable pontoons, which can only carry the same number of waggons, whether empty or full.

224. *Connection of the spans with one another.* 1st *Fixed spans* (Pl. XVI, figs. 10 to 14).— This is naturally effected by the elements themselves of the

ways, whether for rail or road. For the former, where the inverted T rails rest on longitudinals $9'' \times 9''$, a short rail *m n* (figs. 10 to 12) 10 feet long, together with its longitudinal *l*, *l*, is fixed down by four jointed stirrup-irons *e*, *e*, *e*, *e*, two on each boat, to the lower row of longitudinals *pq*, *p'q'*; these stirrup-irons are tightened up by the keys *c*, *c*, *c*, inserted under the rails. In the roadways the adjusting screws V take the place of the keys in tightening up the stirrups, which fix the ten feet longitudinals *l'*, *l'* (figs. 10, 11, 13 and 14); in addition the chains *h*, *h* (fig. 13), rendered taut by means of the bent lever *c*, *c*, strengthen the whole.

2nd *Moveable spans.* — It was necessary in this case, that the connection should be easily undone and again made good; the means adopted were :

On the railway (Pl. XVI, figs. 17, 18 and 19). — 1st The strong fish-plates EE with vertical hinge C,C, 4′ 6″ long, clipping the upper longitudinals, and fixed by the keys *r*, *r*; 2nd the key-bolts B, fastening the rails to chairs with a single jaw (fig. 18); 3rd the large underneath bolts V, worked by means of the levers λ, λ.

On the roadways (figs. 15, 16 and 18).—1st The long levers L, brought down upon the upper longitudinals, and fastened with the keys *k*, *k*; 2nd the guiding posts ϖ, ϖ (Pl. XV, fig. 4, and. Pl. XVI, figs. 14 and 16), along which is established the contact of the moveable spans, either with each other, or with the adjoining fixed span, have their ends rounded off, and a friction roller ρ, ρ, to assist in getting the moveable spans into position.

225. *Approach slopes. Railway.* — The difference of level between the highest and lowest water is 16′ 6″ (it has even at times reached 20′, but the conformation of the river has in this district been altered since then); however it is now but seldom that the water level attains either extreme, nevertheless it scarcely ever remains the same for more than a few days at a time. The incline of the approach slopes of the railway, 70 yards long, varies between a descent of 1 in 29 and an ascent of 1 in 31 corresponding to the lowest and the highest water level; and with mean water between 1 in 125 descending and 1 in 40 ascending. Each inclined plane, moving on the hinge R (Pl. XVI, figs. 5, 6 and 7), is supported on eight pairs of upright fixed screw-bars *t*, themselves resting against the beams P, P, and fitting into the socket V; it being hung on to the screw-rod *t*, by the ties θ, θ, the cross bar T, and the moveable nuts *r* (figs. 1, 2, 3).

The height of the bearing beams S, S, on which the inclined plane rests, is regulated at each end of them by means of a winch handle μ, working the bevilled gearing *r*, *r*.

The pontoons forming the shore spans likewise carry the line by means of bearing beams, of screw-bars, and of the upright beams P, P (Pl. XV, figs. 3, 4 and 5); this making the total length up to 116 yards, over which may be distributed at need the difference of level to be made up, and the incline divided over. But in order not to have to regulate the slope too often the longitudinals are connected by the hinges *u* (Pl. XVI, figs. 20 and 21), on the last fixed tressle-frame as well as on the first tressle of the pontoon; the load being thrown on to their bearing beams by means of the springs ρ, ρ.

Thus the level of the rails may be broken, and the slight variations in the water level spontaneously compensated for by the alterations in the incline of the articulated portion, while the load still bears upon all its supports.

Roadways.— The approach slopes to them are formed in a similar manner, only more simply. Their length is less, 38 instead of 70 yards, and consequently the incline is greater, this does not however exceed 1 in 20; there is no hinge at the end, nor any suspending screw bar; the load is borne directly by the tressle-frames by means of the bolts *b* (Pl. XVI, fig. 2), fitting into the holes *i*, bored in the uprights and in the bearing beams Q, these last being raised and lowered by means of winches.

On the pontoons of the shore spans, as on the rest of the bridge proper, the two roadways rest upon the same bearing beams SS (Pl. XV, fig. 5), as does the railway; these, strengthened in their central portion by the iron tie rod αβγδ, are carried on the intermediate tressle-frames by means of fixed screw bars and moveable nuts, and on the end tressles by the aid of bolts, exactly as on the approach slopes.

Experience may perhaps lead to some of the details of construction being modified, but the principle of the solution of the difficulty, designed and carried out by Mr Basler, engineer in chief of the Palatinate Railway, is in itself very remarkable. The haulage on the bridge is performed by special locomotives, of four wheels coupled, which on the level can draw 370 tons, and about one tenth of this up an incline of 1 in 29.

The trains necessarily cross the bridge very slowly, at a walking pace in fact; this however matters but little, the object being to pass over without obstruction, and this has been fully realized. The passenger trains travel across in perfect security; the line giving slightly under the engine, but without causing any rebound at all.

Everything tends to show, that the time may be patiently awaited, when the increase in the traffic will justify the construction of a fixed bridge.

§ VIII. — **Junctions in connection with manufacturing works.**

226. One of the most striking proofs of the serious inconvenience that change of carriage imposes on industry is the rapidity with which branches, with the ordinary or main line gauge, and placing factories in direct connection with the railway-system, are on the increase. There is on this score a close connection between this subject and the preceding one. We will therefore examine it now, although its place in a certain view follows more properly the subject of points and crossings.

An establishment of any importance, situated near to a railway, does not hesitate to make a considerable sacrifice in order to form a connection therewith, and without which it may very properly be looked upon as deprived of a great part of the advantages attached to this vicinity. Connecting lines of a reduced gauge, though useful, and cheaper, are only the exceptions; as generally the object is in fact less to reduce the slight expense of transport properly so called, than to do away with the costly staff and the loss of time consequent upon transhipment.

The right of manufactories to construct these connections has in France been laid down in the terms of the concessions of railways (article 62), following the decree of June 11th 1859, in words which are somewhat equivocal; since they seem to imply the intervention of the authority of government only in case of disagreement between the proprietor of the factory and the company that works the railway. But in fact this intervention always takes place, in as much as no works which alter the condition of a line, and which affect its security, can be executed except in virtue of an authorization from the proper minister. The railway company and the manufactory generally agree upon the principle of the connection, which is very simple, as it is based on the agreement of their mutual interests. It is only upon details that any discussion can occur, the factory endeavouring to curtail some expense which the company consider necessary; but the former nearly always end by accepting the conditions imposed upon it, and which it is impossible to gainsay, as they are demanded on the score of public security.

These conditions simple in themselves are the only ones we have to examine in this place.

The establishment of a connecting line often necessitates the crossing of a road, or even a main thoroughfare (233); and the authorization for which must be specially obtained in the ordinary manner.

Necessarily the service of the factory branch must be entirely subordinate to

that of the main line; and likewise, exclusive of the communication between them, they should be completely isolated from one another. Thus they ought to be separated by a fence, with a gate at the point where it is crossed by the branch line, similar to a level crossing (242), to be locked, and only opened at the time required. A moveable stop-block (228) placed near the gate should always be kept closed to prevent any waggons of the factory, impelled either by the wind, by the ordinary working of the line, or by any other reason, from running on to the main line. The switches of the points of communication between the two lines, made to leave the main line free, ought to be padlocked in this position and only opened towards the factory at the time of using it; excepting at this time the connection ought to be, as if it did not exist.

The moveable stop-block, though it suffices as long as the connecting line is on the level, or better still inclined towards the factory, may cease to be so if the slope is towards the main line, in which case special precautions are necessary to protect the latter; of this we shall have an example shortly (227). Too great an inclination in this direction may present a serious obstacle to a connection.

The position of a factory below the level of the main line may also lead to special arrangements being adopted. The connection of the sugar works at Douzy with the line from Charleville to Thionville on the Eastern of France presents an example of this kind. The line at right angles, which connects by means of turntables the factory with the station lines, is 3′ 6″ above the sugar works; this difference in level is compensated for by means of a carriage running on a line below, having itself a short length laid upon it to receive the waggons.

227. Works may be connected, either inside of stations, or on the open line; by turntables, or by switches; with a double, or with a single line of railway.

1st *Connection in a station. — With a double line.* — 1° This connection is most easily effected in this situation by means of a turntable.

A special line communicates at one end through the turntables with the line from the factory, and at the other with the main line on the same side, by points taken from behind by the trains; whilst working this is protected by signals at a distance from the station.

2° The connection by means of turntables presupposes but a small circulation; it is often however necessary that several waggons at once, drawn by horses or even by an engine, should be able to pass between the main line and the factory. In the case of a double line with the junction in a station no other difficulties can arise, than those resulting from the situation of the

works; the connection with the main line should be made by a curve of a tolerably large radius, a condition which might in certain cases render a direct connection too expensive, and cause the preceding solution to be adopted notwithstanding its insufficiency. Under other circumstances the difficulty is overcome by means of a return line, as with the Mairupt factory on the line from Charleville to Givet, between Deville and Revin; *mnpq* (Pl. XVIII, fig. 2) being the return portion.

With a single line of rails.—The connection in this case, being in a station, is effected in the same way; as the single main line is always doubled at these places, it is with the line situated on the side of the factory that the special branch from it is connected, either directly, or by means of a turntable. The only objection to the introduction of a set of points is, that in certain cases it might be met by the trains; but as this is the constant condition of railways with a single line, the addition of one more, and which besides the trains always find padlocked, is but a slight inconvenience.

2nd *Connection on the main line between stations.* — This connection being outside the station, or more exactly beyond the signals which guard it, evidently requires some special arrangement to protect the main lines, whilst being used for the factory. Signal posts are naturally placed at the proper distance, the working of which, as well as that of the points, and of the gate, are entrusted to a special man, who may be made use of as a level-crossing keeper. In fact a sort of elementary station is established, similar to those stopping places, which are available for passengers; these were first established in Germany, and at present many exist on the Eastern of France railway, to the great convenience of the rural population, if not to that of the company also.

This connection intermediate between stations causes therefore some special expenses in first cost and in maintenance; it is not within the power of every one, large and important factories only are able to support these expenses, which naturally are borne by them; this cause of inferiority may therefore also be added to the others, which already weigh upon small manufactories. The working of a railway, with a large traffic and at a great speed, can only permit with reserve these manufacturing branches, that form their connection outside stations; and it is fortunate in this respect, that it is not in the nature of these branches to increase much in number.

With a Double line of Rails. — When no communication exists between the two lines, and this is often the case, only one signal is required. As the factory should have access to the second line, this is effected, but very indirectly by means of the stations between which the works are placed. Thus any traffic in a contrary direction is avoided, and the goods are conveyed to one

or even both of the stations, though at the cost it is true of a more, or less considerable increase in length of transit.

The connection by means of a turntable of the iron works of Liverdun (Moselle) (Pl. XVIII, fig. 1) affords an example of this arrangement; the works are connected with the up line only, by means of a set of points A placed according to the general rule, so that the main line trains shall never meet them. It follwos from this arrangement that waggons from the works, intended for the down line, are conveyed by the up train to Liverdun, whence they are taken on by the down train.

In order still more to leave the Liverdun station clear, the return waggons for the works by the down line are sent on thence to the Frouard station, where they are passed on to the up line and by it to the works. This is however but a working detail, which may any day be altered.

A strong wooden fixed buffer MN protects the main line against the waggons from the works. The connecting line AB communicating with the works by the turntable P is on the level.

The connection of the foundry of Jarville near Nancy (Meurthe) (fig. 3), is established on the same principle. The line AB, which does not extend as far as the works, serving only for the loading and discharging quays PP,QQ, is connected only with the down line; the waggons leaving the quay and intended for the direction of Nancy are picked up by the down trains, and taken on to Varangeville, whence the up trains carry them to their destination; those which arrive by the up line continue their journey to Nancy, and are taken back to the works by the down trains.

If it is necessary to connect the works with both main lines, there are only two methods of effecting this, 1st to connect the works to the main line M next to them, and this line with the other one N by means of a set of points BC, so placed that they may be taken from behind by the trains on each of the main lines (fig. 5); or 2ndly to merge the connecting line at one end, A, into one of the main lines, and at the other end, B, into the second one (fig. 4). The latter method is much the simplest in working, which is of the same nature for the trains in either direction.

Supposing a waggon from the works has to be taken up, the train is stopped and uncoupled at the place that this waggon should occupy, according to its destination; the head of the train then goes past the points A or B (fig. 4), and is backed on to the siding, where the waggon is coupled up; it then returns by the same way to recover the tail end, which being fastened up, the train proceeds on its journey : the same manœuvre takes place when leaving a waggon. The pointsman, having but one switch to attend to, has no excuse for

leaving it, and retains in his hand the lever of it during the whole time the engine and the waggon is upon it.

With the first named method (fig. 5) the working is exactly the same for the trains on the main line M, next to the works, but it is much more complicated for those on the other line N; there are then two cases to distinguish between.

1st If a sufficient number of men are available, the waggons to be taken are pushed by hand one by one from the connecting line AU on to the main line M; the engine with the head of the train then backs through the points CBA to take up the waggons, which it carries on to the line N; similarly the engine backs on to the line M any waggons to be left, which are then pushed by hand on to the line U one by one.

2ndly If hands are wanting, all the working must be done by the engine. The train stops at a sufficient distance from the points C; the engine then is unfastened, and advances alone along the line N till it is abreast of the waggons to be taken up on the line U, to which it is attached by a tow rope; by backing it draws these through the points A on to the line M taking care to pass a sufficient distance beyond them; the tow rope is then unfastened, and the engine proceeds to take up the waggons by means of the points CBA. A similar operation with the tow rope must be gone through, when waggons are to be left.

In both cases the working occupies a long time, and imposes a considerable delay upon the train; the line upon which it is not travelling as well as the other is occupied for some time, and all traffic is completely intercepted during the whole of it. Moreover as each of the three points must be worked several times, the pointsman is obliged to go from one to the other, and cannot keep the lever tight up during the passage over each of them; hence arises a risk of running off the line. Against these serious objections there can, as against the double direct communication, be only shown the presence of the one oblique through-crossing T (fig. 4). Through-crossings no doubt have their objections (258), but points and crossings have also theirs, and the indirect communication requires three of the latter instead of two. Now it is very rare that a running off occurs on an oblique through-crossing, if carefully maintained, as the long experience of the Eastern of France Railway shows; for a large number of them exist on that part of its system, which was constructed by the Ardennes company, there are also several at the other large stations on the rest of their system : whereas nothing is more frequent on the contrary than running off the rails at the points while working them. While as to the danger of collision by means of a signal overlooked, or run through, it is the inevitable consequence

of the relative situation of the lines, and is less with through-crossings than with a special communication between the two main lines; since the waggons occupy for a lesser period the line over which they pass in order to reach the other.

It cannot besides be denied, that in connecting works with the line farthest from them, whatever may be the mode adopted, there is a greater risk of accidents incurred, than with simple communication with only the one next to them. This double communication is as much as possible confined to particular cases, affording almost as much security as a complete station.

Thus it is that the following arrangement was authorised in 1866, after considerable consideration, for the transformation of the goods depot of Remilly on the line from Charleville to Thionville, originally connected with the up line only, into a goods station and a stopping place for passengers (fig. 6). The junction line AO, which is common to the siding lines OP, OQ, is connected at A to the up line, and at B to the down one, and crosses the former at T. The responsibility of the official in charge of the working thereof, and the assistance of the staff at his disposal, afford as much security as that of a proper station.

Double communication is not however absolutely confined to cases of this kind; it may be permitted with works causing but a moderate amount of traffic, which is easily regulated, and for which connection with both the main lines is altogether necessary. Such is the case shown in (fig. 11), where a stone quarry is placed in communication with the line from Paris to Mulhousen, between the stations of Villiers-sur-Marne and Emerainville. This connection is formed similarly to a stopping place for passengers, except that only goods trains stop at it; they are protected during their detention by signals, at a distance of half a mile on the Paris side, and three quarters towards Mulhousen, in consequence of the fall towards Paris.

A more important junction, that of the factory at Graffenstadt (Bas-Rhin), has been established under similar conditions, viz., with a double connection AB, CD (fig. 10); as there are two siding lines in each direction, the working between them and the main lines is very simple; the engine after backing the waggons on to one line, can immediately take up those which are already prepared on the other (*).

b. — ***With a single line.*** — A connection intermediate between two stations where there is only a single line cannot be permitted without mature consideration, as it entails a set of points on the open line, and which consequently being met by the trains in one direction, are without the guarantee afforded

(*) In France the trains always keep to the left, as is shown by the direction of the arrows with the sole exception of the Strasburg and Bâle line, where they keep to the right.

by the presence and responsibility of a guard, having a certain position; but to be obliged to form the connection within a station is often tantamount to a prohibition, which might entail consequences so disastrous upon the works, if not upon the railway itself, that the ministerial permission cannot be witheld. Many such exist on the single line portions of the Eastern of France Railway, and, thanks to the precautions taken, not only has no accident been caused by them, but they have not even deranged at any time the working of the line.

For all material purposes it is in fact establishing a species of elementary station; the line coming from the works, either directly or by means of a turn-table is connected by points, not to the main line itself, but to a siding, from nine to ten chains in length, for example; this is placed in communication with the main line either at one end or at both.

The double communication ACB, applied for example to the junction of the glass works at Richemont on the Metz and Thionville line (Pl. XVIII, fig. 7), and to that of the Tillots mine on the one from Charleville to Thionville (fig. 9), greatly facilitates the working to be gone through in taking up or leaving waggons; moreover, if this line ACB, from which the sidings proper branch off, is kept clear, a train, finding the switch, as it meets it, wrongly placed for it, would without further inconvenience resume the main line at the other end. These advantages are quite sufficient to compensate for the slight draw-back of an additional set of points. It is needless to add, that it is just as necessary in this case to have the separating paling with a gate and lock to it, padlocks on the switch-bars, a moveable stop-block, and signals, two only however; and also quite as indispensable, that the rules with regard to pre-cautionary measures be strictly observed, as with a double line, perhaps even more so.

At Tillots (fig. 9) the main line is on an incline of 1 in 100, as well as the loop line AB and the portion CD common to both siding lines; but those marked DE, DH, and FG are on the level.

The connection of the iron works of "La Providence" with the line from Longuyon to Longwy, on the Eastern of France, is shown in (fig. 8); the branch line having a descent of 1 in 200 towards the railway, it was necessary to guard against waggons escaping from the works; for this purpose a blind siding, with an up gradient, and an earthen stop-buffer, K at the end, and to which the points are always open, starts from the junction line AMB.

It sometimes happens, that a signal cannot be placed at the regular distance without coming too close to a station, this distance must then be somewhat reduced.

The Eastern of France system possesses at present more than one hundred

connections with different industrial works, of which more than fifteen are outside stations; the number is besides daily on the increase,

The Northern of France Railway, traversing in its course some of the busiest parts of that country, has more than one hundred and twenty of them; but they are nearly all within stations.

§ IX. — Moveable stop-blocks, and fixed buffers.

228. The main lines of a railway should not only be protected against an accidental incursion of waggons from works with which they are connected, but they should also, and more especially, be guarded against all rolling stock placed upon sidings with in the enclosure itself of the railway. Junctions with works are therefore in this respect but one particular case of a general condition. As the safeguards used are always the same, and as they form an accessory of the permanent way, we will describe them here in order not to have to return to them later on.

A railway carriage, especially if it is lightly laden, and its breadth considerable, may be set in motion merely by the impulse of a strong wind. Waggons therefore on a siding, particularly if it is at the top of a steep incline, may occasion very serious accidents, if they were thus let loose upon the main line, where their weight, despite the retarding action of the increasing resistance of the air, would cause them to attain a very considerable velocity.

The danger would arise particularly on single lines, or on double ones when worked the reverse way; since the concussion between the loose waggons and a train might be in virtue of the sum of their velocities. A blow from a buffer while in motion, or the breaking of a coupling on an incline, may cause the same consequences, or even more serious ones, in as much as the mass of the train let loose, and which the brakes are sometimes powerless to control, is often greater; here however we shall only treat of the first named cause.

Special precautions ought to be taken to retain in their places waggons stationed on the top of an incline, especially when the wind blows with any violence. To tighten up the brakes is the first measure to be taken, but all are not provided with them. To lock a wheel is a sure prevention, but in general much neglected, although it is regularly done upon several foreign railways; in Spain and in Italy for example, where it is not asserted, as in France, that it exposes the carriages to damage which a little attention might easily avert. This precaution is not used, it is true, with wheels having solid discs, which are very common in Germany even, with goods waggons, though but rare in France unless for carriages of fast trains. Simple hand blocks, like the

brakes and locking, have the advantage of acting immediately on the carriage and of preventing its attaining a certain speed, which, once acquired, it is often difficult to arrest. But blocks give way, and are apt to fall out; the man in charge then, not having one at hand, uses something altogether insufficient, such as a ballast stone, which is too small and unsteady.

On the Brunswick Railway the block is made double and acts on both wheels; it is formed of two wedges, similar to the shoes of a brake, joined by an iron tie-bar; these are placed upon the rails, and small downward projections, each furnished with a pressure screw, keep them in position : this method is surer, but it has the inconvenience of being cumbersome.

The hand-block in fact offers but little security; and preference is therefore given as much as possible to an obstacle, which is fixed at a certain point on the line and which can be opened and shut at will. But these moveable stop-blocks can only be rendered absolutely effective, if the carriages they are to restrain are placed at but a short distance from them. In fact the latter must not before reaching the obstacle have acquired from any cause whatever a speed sufficient to over come it, and yet continue their course on the line itself.

Accidents of this kind are of tolerably frequent occurrence on lines with heavy gradients. The electric telegraph has sometimes allowed the consequences thereof to be warded off, by warning the station towards which the escaped waggons are running of its danger; it at once prepares for the reception of its unwelcome guests, by clearing the line, and if necessary by retarding the departure of the trains. There are however cases where no amount of presence of mind is of any avail, and where a disaster would be inevitable.

229. *Theoretical height of the obstacle.* — The height of the block, when treating of non-elastic bodies, and where the centre of gravity is supposed to be placed on the centre line of the wheels, is connected very simply with the speed and the mass of the carriage.

Let us first consider a single pair of wheels only of the radius r (Pl. XIII, fig. 36). Let $\frac{P}{g}$ be the total mass, the wheels and their load; $\frac{p}{g}$ that of the wheels and the axle; k the radius of gyration of the revolving parts, the wheels and the axle; V the velocity; and suppose the general centre of gravity placed on the axis of the axle.

The vis viva before the shock is

$$\left(\frac{P}{g}+\frac{pk^2}{gr^2}\right)V^2, \quad \text{whence } \frac{P'}{g}V^2; \quad P' \text{ being the weight } P+p\frac{k^2}{r^2}.$$

As the bodies are supposed to be non-elastic, the concussion of the wheels, acted upon with the velocity V, against the obstacle h in height, destroys the component V sin α.

In order that the obstacle be not overcome, it is necessary, that half of the vis viva after the concussion, $\frac{P'}{2g} V^2 \cos^2 \alpha$ should be less than the resisting power of gravity Ph; and hence than the limit, since $\cos \alpha = \frac{r-h}{r}$,

$$V = \frac{r}{r-h} \sqrt{2ghr \frac{P}{P'}};$$

with $r = h$, then $V = \infty$, which is manifest.

If V exceeds this limit the mass continues its movement, and describes, with the initial velocity V cos α, a parabolic trajectory; the force of gravity gradually destroys its vertical velocity V cos α sin α, and imparts to it another, equal and contrary; so that at the moment the wheels on reaching the point A′, at the distance $AA' = \frac{2V^2 \cos^3 \alpha \sin \alpha}{g}$, fall upon the rails, they have, as at the moment after striking the block, the velocity V cos α, but forming with the horizontal the angle $360 - \alpha$. The vertical component V cos α sin α is suddenly destroyed by the concussion on the line; after the second blow the mass therefore only possesses the horizontal velocity V $\cos^2 \alpha$.

The total loss of vis viva, due to the collision with the block, is therefore

$$\frac{P'}{g} V^2(1 - \cos^4 \alpha) = \frac{P'}{g} V^2 \left[1 - \left(1 - \frac{h}{r}\right)^4\right].$$

For a vehicle with a pair of axles the conditions are different (fig. 37). Let $\frac{P}{g}$ be still the total mass, and $\frac{p}{g}$ that of the wheels and axles; suppose the tcentre of gravity G to be placed on their centre lines, and in the middle thereof, and let it be granted, that instead of the mass $\frac{P}{g}$ two others $\frac{P}{2g}$, concentrated respectively on the axis of each axle, may be substituted for it.

After the concussion with the block the velocity of the front pair of wheels is V cos α, forming with the horizontal the angle α, that of the hinder pair is V $\cos^2 \alpha$, but is horizontal. The whole mass in fact turns therefore, during the moment following the concussion, round the instantaneous centre of rotation T, the point of concurrence of the radii TM, AT, the lengths of which are to each other as 1 is to cos α, or as the velocities V cos α, and V $\cos^2 \alpha$ of the

centres A, B; velocities, which according to the admitt hypothesis, are also respectively those of the front and of the hinder half of the mass.

The half of the vis viva after the concussion is therefore,

$$\frac{P'}{4g} V^2 \cos^2 \alpha \,(1 + \cos^2 \alpha), \quad P' \text{ still representing } P + p \,.\, \frac{k^2}{r^2}.$$

A value which ought, in order that the block be not overcome, to be at most equal to the resisting force of gravity, $P\frac{h}{2}$; the general centre of gravity G being only raised to the amount of $\frac{h}{2}$, when the hind wheels are elevated to h.

$$\text{Whence } V = \frac{r}{r-h}\sqrt{\frac{2gh}{1+\left(\frac{r-h}{r}\right)^2}\cdot\frac{P}{P'}}.$$

But the block may still be sufficient, though the first pair of wheels might have got over, provided it be not surmounted by the second, slackened in speed, as well as is the whole mass, by the first concussions of the former against the block, and then upon the ground. The whole mass then only possesses, as already stated, but one horizontal velocity $V\cos^2\alpha$, with which the hind wheels approach the block, which is suddenly transformed for them into $V\cos^3\alpha$, inclined at an angle α to the horizontal, and for the front wheels into $V\cos^4\alpha$, horizontally : the half of the vis viva after this last concussion is

$$\frac{P'}{4g} V^2 \cos^6 \alpha \,(1 + \cos^2 \alpha).$$

This active force would be completely neutralized by that of gravity, $\frac{Ph}{2}$; and consequently the height h of the block will be effective, so long as the velocity does not exceed the limit,

$$V = \sqrt{\frac{2gh}{\cos^6\alpha\,(1+\cos^2\alpha)}\cdot\frac{P}{P'}} = \frac{r^3}{(r-h)^3}\sqrt{\frac{2gh}{1+\left(\frac{r-h}{r}\right)^2}\cdot\frac{P}{P'}}.$$

In practice the height, which is variable, of the centre of gravity above the centre lines, the suspension springs, and the elasticity of the substance of the wheels and of the blocks, modify the data of the problem. Besides the only object here is to give a summary idea of the action of these blocks; experience ought to determine their actual height.

230. These stop-blocks may be differently arranged. In England, for instance they are generally composed of a block of wood, working round an upright pivot, or on a horizontal hinge, which turns down upon one of the rails and butts against an iron pin. The block acts therefore upon one only of each pair of wheels; it stands up usually from three to five inches, and sometimes as much as ten.

In France preference is given to the model adopted first on the Lyons Railway (Pl. XIII, figs. 29 to 33, also 25 to 28). It consists of a wooden frame fixed to a sleeper by two hinges; when down the side *c*, equal in length, excepting the small amount of clearance necessary, to the working width between the rails, lies between them and below the bottom of the wheel-flanges; when raised it rests against two long prop-bars *t*, *t*, and its two extremities, shod with an iron plate, prevent the further progress of the flanges: the block stands up from ten to eleven inches above the rail-level, which appears amply sufficient. Even if the first pair of wheels should get over the block, the second ones would be brought up by it, in consequence of the loss of velocity due to the first concussion; it is absolutely necessary however, that the block should be constructed of sufficient solidity to resist the concussions, which is not always the case.

In Germany on some railways, the waggon is moored to the line by one of its coupling chains. A bolt with its broad head below is fixed upright in the middle of one of the sleepers, and carrying at its upper end a short piece of chain, into the links of which the coupling hook is fastened. This method has one inconvenience, the unhooking is difficult if the chain is stretched tight, and the tension may be considerable if several waggons are coupled together.

231. *Fixed Buffers.*—The arrangement of buffers properly so called, fixed impediments placed at the end of blind sidings, varies naturally according to the object of those lines, with the violence of the concussions the buffers may be exposed to, and the degree of absolute necessity to protect what lies beyond.

Thus fixed buffers built at the end of main lines, and in terminal stations, to protect their buildings and approaches, are constructed very solidly and furnished with spring buffers, placed at the same height as those on the rolling stock; no doubt a necessary precaution, but one that is entirely directed against an accident which is very rare, as the locomotives ought never to be left to themselves, and their drivers ought always to have sufficient control over them to prevent the buffer being reached.

Sometimes indeed on the main line towards the end of a passenger station,

even of no great length, is placed the pit of a traverser, as is the case with the reversing station at Berne: this arrangement is open to criticism, it has however the advantage of obliging the engine driver always to approach the station with much care, which is of course a guarantee in its favour.

Different heights of buffer, differing also in solidity of construction are required on service lines; if single waggons only are to be run on to them, the obstacle may be low in height, sometimes the rail ends are merely turned up, or in other cases a sleeper only is fastened down upon them. But blind sidings, that is where the main line is double, require a substantial buffer; as the engine driver, while backing the train several hundred yards off, cannot always stop it in time, either through the signal to do so not being given to him in time from the hind part of the train, or else through his own tardiness in executing it. The protection in this case is sometimes merely a mound of earth, which has the double advantage of being economical and of deadening the concussions.

A better result may however be obtained by embedding in the face of the mound a wooden buffer-frame, which, being thus backed up by the earth and to which it transmits the blows, may be constructed of timbers of reduced scantling. Figures 18 to 24, of plate XIII illustrate one of these compound buffers, composed of the four uprights *p*, *p*, carrying the cross buffer-bar C, of the backing boards *n*, *n*, of the ties *t*, *t*, and of the bottom pieces *s*, *s*, upon which the whole rests; sunk into the ground it does not appear possible for any concussion to upset the frame without also upheaving and casting back the mound of earth in which it is embedded. Small slope walls *m*, *m*, in front, on either side of the wooden frame, retain the earthen backing in its place.

§ X. — Proposed precautionary measures against running off the rails at certain dangerous points of the line.

232. This appears the time to say a few words on a question, which has been often, and even recently, discussed; viz., the application at certain points, either dangerous or considered as such, of some measures suitable for the prevention of trains running off the rails, and, if off the rails, to keep them on the line.

Guard-rails properly so called, that is placed on the inside of the line, are considered, almost unanimously, as tending to aggravate rather than to diminish the consequences of an accident of this kind, or of the breakage of an axle.

In France the Minister of Public Works has decided, in his circular of March 2nd 1859, that the use of guard-rails, provided for by the regulations of Novem-

ber 25th 1846, and always compulsory with level crossings, shall not extend to the passage of large viaducts and of high embankments.

"Engineers" says the circular "are nearly unanimous in acknowledging, that the "employment of guard-rails is a preventive against running off the rails of at least very "doubtful utility; and on the other hand, that this measure affords more cause of "danger than of security, when applied to parts of a line which are not subjected to "a special surveillance."

In the same circular, and by the advice of the general council of the "ponts et chaussées," the minister requires government inspecting engineers to study the means of preventing running off the rails, and of diminishing the evil consequences arising therefrom "on all dangerous parts of a railway, "such as viaducts, high embankments, abrupt mountain sides, banks of "rivers, curves of small radius, etc.; care being taken to distinguish between "the measures to be adopted for lines already constructed, and for those yet "to be made."

This inquiry did not result in any propositions clearly laid down; in fact it is difficult to see how it could have been otherwise.

All that can be said is, that guard plates, or parapets, properly constructed, would often be a safeguard, and never a cause of aggravation of the accident; a train off the rails would run against them too obliquely to render the concussion dangerous. However the employment of such measures is still quite exceptional, even under circumstances where they would be the cheapest and are, apparently at least, the most needed; viz., on large viaducts having but a slight parapet railing.

On the whole of the Eastern of France system, for example, the great viaduct of Chaumont is the only one that has the outside guards. They are formed of longitudinal balks *b*, fastened by lewis bolts and by angle-irons *c* to the parapet stones (Pl. XIII, figs. 34 and 35); these wheel-guards should be sufficiently distant from the rails not to inconvenience the maintenance, this distance ought apparently to be not less than 2′·6″; their height above rail-level ought not to exceed from 12 to 14 inches.

On embankments, composed of a shifting material, the fixing of these guards would entail considerable expense; in general the less justifiable in as much as an obstacle would thereby be created to the drainage of the rain-water, he most essential condition for a good permanent way.

This is not the case where embankments are composed, either entirely, or the outer half only, of stones of sufficient size to allow of what is in fact a dry retaining-wall being constructed at a slight expense, and by which the slope is

considerably diminished; these walls may be then continued up and form solid parapets, thus fulfilling the object desired. Very many examples of this kind may be met with; but this is not the place to describe them, they come rather under the head of works of art.

In fact, though the sensation of being in some sort suspended on the edge of an abyss, dependant only upon the slight projection of the wheel-flanges, is anything but encouraging, yet experience every day proves that the danger has been exaggerated. Lateral guards may somewhat re-assure the eye, one ought however rather to endeavour to render their use unnecessary, than to increase their number. Especial care ought to be taken at those points, where the consequences of running off would be most disastrous, to guard against such an occurrence.

The true safeguards against this class of accidents lie therefore in particular attention to the maintenance, and in the measured speed of the trains, especially in curves.

§ XI. — Level-Crossings.

233. It is scarcely necessary to recall the fact, that, where a railway and a road cross one another, in order to preserve uninterrupted the traffic on each, it is requisite, 1st that the projection of the rails above the road must disappear, and 2ndly that a free passage should be left for the flanges of the wheels on the ailway.

Hence the need of guard-rails, placed parallel to the main-rails, and having their extremities opened out, or bent towards the inside of the line, for a distance sufficient to afford a clear entrance for the wheel-flanges, so that they may strike the former only very obliquely.

With a gauge of $4'\cdot8\frac{1}{2}''$ in the clear between the rails, and a distance of $4'\cdot5\frac{1}{2}''$ between the insides of the tyres, a pair of wheels, in their mean position, have $\frac{4'\cdot8\frac{1}{2}'' - 4'\cdot5\frac{1}{2}''}{2} = 1\frac{1}{2}''$, between the inside of each of their flanges and the face of the corresponding rail-head. This then must be the minimum width of the groove, or in other words it must be equal to the sum of the breadth of the flange and of the half-play of the line. In practice it is slightly more, $1\frac{3}{4}''$ to $2''$, to compensate for the small difference which exists, on various lines, in the distance between the two wheels on the same axle, as well as, in the rolling stock of the same railway, for the minor ones, such as a slightly strained axle, or a flange bent inwards, etc. The Dresden meeting recom-

mended as much as $2\frac{5}{8}$ inches (*). It is unnecessary to add, that in curves of small radius, this dimension is increased by the half of the extra width allowed between the rails (199, 200).

For a long time it was considered necessary to pave the central portion, even in the crossings of roads ballasted with stone, for fear lest a piece, getting wedged in the groove, might cause a running off the rails. At present however this expense is often done away with, a slight one it is true, but still of little use; as the very great surveillance bestowed upon level crossings in fact renders an accident of this kind very improbable.

The guard-rail is almost always one of the ordinary ones, only laid without any inclination; there is an advantage in laying it slightly above the level of the main rail, to relieve the latter from the action of the wheels of ordinary carriages. With the chair rail this extra height is obtained by a slightly increased thickness at this point in the bottom of the double shoe, which receives the two rails; with Vignoles rails, they are both on the same level in general. Sometimes, when it is particularly wished to protect the main rail, the guard is composed of a longitudinal balk of timber with an iron plate on the inside next the groove.

224. It would be departing from the object of this work to enter into minute details on a subject so simple. The space, which may be allotted to it, can be more usefully devoted to the examination of those measures which are intended to guarantee the security of the double traffic, while causing it the least inconvenience possible. A question which involves too many different interests to be treated summarily.

The road-traffic, whatever its importance, ought evidently to give way to that on the railway, which ought not to be inconvenienced by the former; their mutual security even demands, that it should be totally suspended when the passage of a train requires it.

Level-crossings are therefore provided with gates, excepting perhaps on purely industrial lines, even when the railway is not regularly enclosed. If the regularity in the running of the trains is not deranged, closing the gates would cause but little inconvenience to the cross traffic, even on lines where the trains are numerous, since it may be resumed almost as soon as interrupted.

No doubt level-crossings, situated just outside stations, are sometimes intercepted for too long a time by shunting going on in the station, or by the

(*) " Vereinbarungen, etc., Bahnbau " art. 8.

lengthened halt of a goods train; but this difficulty may be easily got over by severing the halted train, and by interrupting at fixed times any long working operations, in order to re-establish, if it is only for a few moments, the traffic on the road. The maximum period during which any crossing is to be closed might be fixed in proportion to the activity of the circulation upon it.

The Eastern of France Railway, on the subject of its interior arrangements, ordered on February 19th 1864 the application of the following measures.

1st Whenever a passenger or a goods train, arriving at a station, shall be of such a length as to intercept the circulation on any level crossing adjoining thereto, and that its detention there, according to regulation or otherwise, will exceed five minutes, the station master shall cause the train on its arrival to be divided in two at the level crossing itself, so that the road traffic may be immediately re-established: he will also see, that the crossing gates are again closed before the order is given to re-connect the two parts of the train.

2nd If, during the operation of adding to or of taking off carriages or waggons from the train, which is halted on the level crossing, it is found, that the portion on the crossing has to remain stationary during the whole working, the first thing done must be to divide the train at the level crossing, so as immediately to re-establish the road traffic.

3rd If in the course of working a train, it is found necessary to propel the whole, or part of it, or a locomotive by itself, in front of the level-crossing gates, these must remain closed, but only during ten minutes; at the expiration of which, the station master shall cause the working operations to be interrupted, and the train to be divided at the crossing, so as to allow persons and carriages to pass across the line.

If the operations last more than ten minutes, they must be resumed and interrupted at the end of each fresh period of ten minutes, so that the traffic on the level crossing may never be stopped for any longer than this time.

4th On fair and market days, and whenever there shall be, on the road served by the level-crossing, an exceptional number of carriages and persons detained at the gates by the operations of a train, these shall be suspended at intervals of five minutes.

The application of this system, of periodically relieving level-crossings by interrupting any very lengthened detentions of the circulation, has afforded very good results on the Eastern of France. This principle ought henceforth to be embodied among its definitive regulations, to the benefit of the cross traffic, which may then claim as a right, in case of need, what is now but a simple toleration. (See 240, in the propositions of the Eastern of France railway, art. 10; and 241, in the regulations of the Mediterranean line, art. 10.)

Thanks to these precautions, the level-crossings adjoining important stations, although the most used, are not the ones most complained of by the surrounding inhabitants. With them the chances of danger are almost done away

with, since they are so well looked after; and, if a train is considerably behind time, the station, being informed by telegraph of the delay, keeps the crossing open upon the demand of the passers.

235. This is not however the case with those on the open line; where the crossing keepers, not being advised of any delay in a train, can but expect it as soon as the time fixed for it is come (*).

On some French Railways, even not many years ago, the crossing gates were still inexorably closed the moment this time arrived.

The regulations for crossing keepers stated:

" The gates ought to be closed, and the circulation stopped when the trains are " only at a distance of $1\frac{1}{4}$ miles" (a distance which is often hardly sufficient) " *and* " *when the approach of a train cannot be discerned, ten minutes before the time marked* " *for its arrival. The gates must not be reopened till after the train has passed.* "

The cross traffic was thus made to suffer the same delay as the train, whatever that might be.

As in fact every one benefits, at least indirectly, by the advantages procured by railways, the public ought to yield to their requirements and to give up, when needed, a little of its liberty, provided however that this sacrifice be really necessary. Persons, whether pressed for time or not, who had been made to wait 15, 20, 30 minutes, or even more, for a crossing to be opened, found it somewhat arbitrary, and reasonably so, that they had been kept prisoners for a train, which had only made its appearance a quarter or half an hour after their arrival. It is true they were not aware of this, but might they not have easily ascertained it?

Happily there are a very great number of crossings, where from their situation the keeper is enabled to ascertain whether any train is approaching; in these cases therefore it has been possible, without compromising any thing, to soften down whatever there was excessive, not to say intolerable, in the foregoing regulation.

In France the gates, whatever their ordinary state (238), ought to be closed before the hour named for the passage of the trains (5 minutes, on the Mediterranean system) (**); they are not however absolutely so till the train is coming.

(*) There can be no regulation fixed time for those goods trains which stop when required. But the keeper knows from what time he may expect them.

(**) According to the " Vereinbarungen " (" Zustand der Bahn " art. 14) in Germany the gates ought to be closed 3 minutes before the *passage* of the train; all crossing of animals should be forbidden for 10 minutes previous.

The regulations of most of the lines are now worded in the following manner:

" When asked to open the gates, *the keeper should make certain that the line can " be crossed before the arrival of a train*, in which case he may open the gates, com- " mencing with the outlet one; he must close them again immediately " (240).

A rather vague arrangement, which sometimes leaves too much to the judgment of a subordinate, and one which can be applied in an absolute manner only to lines in an open country and with long straights. The difficulty however, we may add, for crossing keepers to ascertain in time the approach of a train, which they cannot see, is in reality less than it appears. If oftentimes in practice unforeseen difficulties arise, in general also most frequently do they prove less than at first supposed.

Such is the case here; the practised ear of the crossing keepers is a sure guide, who often find a certain indication in the vibrations transmitted by the ground (*). Their hearing alone is left to them in a very dense fog; on these occasions trains, it is true, generally carry their signal lamps lit during the day; but the utility of this is much disputed, as it is objected, that under the circumstances a bulky object, like a train, is always seen, indistinctly though it be, before, the point artificially lighted is visible.

236. The ordinary rule followed with level-crossings appears to detract from this principle, when stated in general terms, ***that the line should be clear, or else protected by a signal.***

For example, the first article of the new signal code on the Eastern of France system (March 1866) words the principle thus.

" The absence of any signal indicates, that the line is clear. At all points and at " all times the arrangements should be the same, as if a train was expected. "

During the passage of a vehicle over a level-crossing the line is not clear, and a signal ought to indicate this, in virtue of the foregoing principle, to the train " which should always be expected "; and which in fact might come, as it is not obligatory to announce special trains or single locomotives.

The new regulations however (March 1866) for the circulation of trains, on the Eastern of France Railway, carefully except level-crossings.

" The main lines " says art. 37 " should always be clear, or covered by signal, except- " ing level-crossings, which are subject to special rules. "

(*) It ought also to be insisted, that, where women are the gate keepers, their head dress should leave their hearing free.

There is good reason in not making the application of signals distance ones which the crossing keepers ought to place at "danger" before allowing any vehicle to get upon the crossing, a general rule. For to admit these, even during the few moments that they are blocked, within the same conditions as obstacles generally on the line, would be derogatory to the principle, that the cross traffic must be subordinate to the circulation on the railway, and not to be placed upon a footing of equality.

This principle is one of absolute necessity, and not merely one of natural precedence. It would doubtless be absurd, that a cart might knowingly stop a train; the stoppage itself and the delay to the train would however be the least of the inconveniences arising from it. For a train when stopped itself becomes an obstacle, and the most serious of all; as such it must be protected and, if this be tardily done, a collision may follow.

Besides a vehicle crossing the line is not an obstacle properly so called. What ought to be protected by signal, is one simply by "vis major." The vehicle is so to speak, a voluntary obstacle, which can and ought to choose its opportunity, and not venture upon the line except with the certainty, that its transit is clear; and this much more in its own interest than in that of the train.

On the other hand the crossing keeper, now-a-days, at least on the continent, generally a woman more or less taken up with her own household cares, might forget to set down the "danger" signal, and so disturb the running of the train; or else, which would be much worse, the signal might be set up too late, when the engine driver had already passed it, and thus a collision would be inevitable.

237. This exception allowed in respect to level-crossings is therefore generally quite justifiable. It is no less necessary however to take special measures, and even if needed to place a signal, at those crossings, where the keeper cannot of himself be certain (235), that a long team or a heavily laden cart has time to get across safely before a train arrives.

On several German railways each train is announced, at the moment of leaving the nearest station, to all the stationary officials of the line by a series of electric bells placed in their respective guard-rooms. This is a useless luxury, and one which may even do harm, as the keepers to hear the signal must always be near their huts. In France, however, every day these sedentary and nearly useless officials are being abolished, as has been done for some time back in England. This objection does not hold good with regard to gate keepers, to whom the German method might be usefully applied.

In France may be found several means, other than by a horn, of announ-

cing the approach of trains to the keepers of gates which are close to stations. On the line from Strasburg to Wissemburg the keeper of a crossing near Haguenau is warned by a bell worked by a wire rope: on that from Strasburg to Bale, near Colmar, the keepers of two crossings close to one another, only one quarter of a mile apart, mutually announce the trains to each other by means of one rope with a bell at either end; this arrangement is sufficient, for, as all trains stop at Colmar, they either have their steam shut off, or else have not had time to get any speed up, by the time they pass over the two crossings. Between Givet and the Belgian frontier towards Namur, on a part worked by the Northern of France Railway, the trains are announced to two crossing keepers by electric bells.

The experience of German railways proves, that in similar cases electrical apparatus may be relied on. The objection, which appears at first sight, of a signal not being transmitted through a derangement in the apparatus, is therefore less serious than it has often been represented; on short lengths also disturbances arising from atmospheric influences are but little to be feared. Nevertheless the principle of announcing the trains to the crossing-keepers is largely carried out only in Germany, where, as has been seen, it forms part of a still more extended system.

In France, in the majority of cases where the application of special measures has been found indispensable, preference has been given to the other principle, of placing distance signals at the disposition of the keeper, with which he may protect the crossing before allowing a vehicle to attempt to pass over. Thus the Eastern Railway has done away with the electric bells, established some years back for some level crossings at Chaumont, Haute-Marne, to signal to their keepers the departure of the trains; as these bells did not act with the necessary regularity they were replaced by signals to be set at "danger" whenever the gates were open and a train expected, but to be put down again as soon as closed. If however a vehicle presents itself, and nothing indicates the immediate approach of a train, the crossing keepers put up the signals, open the gates, allow the conveyance to pass; then close the gates again, and set down the signals.

"Experience" says Mr Ledru "proves that these signals are not a hindrance to "the circulation of the trains; for during the four years they have been erected not "a single train has been stopped."

It might hence be inferred, that they are of but little use, since their object is precisely to stop the trains when needed. Even if they only inspired confidence to the crossing keepers, they would still be a great advantage;

but the company itself recognizes their necessity under the following circumstances :

" On these level crossings " continues their able engineer " the keepers cannot " see the Chaumont station, and it is only by sound, whether of the whistle or of " the running of the train, that they are warned of its approach; these signals are " therefore indispensable to ensure the security of carriages on these two level " crossings. "

" If the general manager's department, which always notifies to me whenever " a train is stopped during its run by permanent way officials, has never yet had " occasion to inform me of a forced stoppage at the Chaumont level crossings, the fact " is due to the special aptitude acquired by their keepers after a certain time in dis- " cerning the approach of the trains.

" It is owing to this aptitude, that so few accidents occur on level crossings; though " their keepers have often to reopen the gates after their regular closing, while " waiting for good's trains, the time of passage of which varies considerably, and " though very few level crossings are furnished with signals.

" Hence I do not believe, that there is any occasion to place signals at all level cross- " ings, where the approaching trains can be seen but from a short distance; lest the " attention of the engine drivers should be worn out by a multiplicity of signals, " which would then be a more serious source of danger. It is my opinion that signals " are only of advantage in protecting level crossings when they are used with great " reserve, and at points which are really dangerous; it is however necessary to retain " them for the protection of crossings which are much frequented, and are placed " under particularly difficult conditions, as are those at Chaumont.

" This is a question of limitation, which experience alone can decide. "

" Paris, December 27th 1866. "

The crossings near to a station may be protected by means of its signals, which must then have a second means of working them for the use of the keeper from his hut; as for example at Vitry-le-François on the Eastern of France line.

There are up to the present time forty seven level crossings on this railway, thus protected by signals either on one or on both sides; of these fifteen however are not provided with any special ones, availing themselves of those attached to the stopping places or rudimentary stations for the local passenger traffic, the working of which is generally entrusted to a gate keeper.

It is hardly necessary to add, that in certain cases a single signal may be sufficient either on a double or a single line, when it is quite clear in the opposite direction.

§ XII. — Management of the gates.

238. The normal condition of a crossing gate may be either open, or closed; in the former case the keeper closes it when a train is due, in the latter he opens it whenever the cross traffic demands it, provided no train is expected. As all trains, whether regulation or otherwise, ought to find the gates closed, the choice between these two conditions must depend upon the relative importance of the circulation on the two ways.

If the trains are very numerous and the road but little used, it is both simpler and surer to keep the gate closed; but if the trains are few and the road traffic considerable, then it is preferable that the gate should be open.

In France the regulation at first was to keep it closed. The law of July 25th 1845 states, "That, wherever a railway crosses a road on the level, gates "shall be established and kept closed, according to the regulations" (art. 4). The order of November 15th 1846, while reiterating this enactment, merely refers in the following terms to the rules to be followed; "the method, the "watch to be kept, and the conditions for working the gates shall be arranged "by the Minister of Public Works on propositions submitted by the com- "pany" (art. 4).

The Railway companies at first only made use with a prudent reserve of the latitude, which a wise foresight had introduced into the law and the order above quoted.

"It appears to me" said the minister even in 1853 (*), "that level-cross- "ing gates should as a rule remain closed, and I only admit of any depar- "ture from this in cases, where there is an exceptionally large traffic on the "crossing, and having moreover a keeper always stationary there."

Four years had however hardly passed, when in 1857 the ministerial sanction was in the case of the Alsace lines given in a decided form to the very opposite principle of keeping all the gates open regularly. Experience has so completely ratified the advantage of this bold regulation, that it cannot fail to be extended, slowly no doubt and with all necessary modifications, to other lines placed under similar circumstances.

Where the circulation is only moderate on the railway but brisk upon the road, it is better in fact to leave the crossing open as much as possible without

(*) Notification of March 31st 1853 to the Government Inspecting Engineer of the Paris and Strasburg Railway.

danger, than to check the traffic on the latter by continually and unnecessarily opening and closing the gates. In this case there is also another advantage in leaving the crossing free; its keeper is thereby more at liberty, and may be made use of on the line, he being needed only to close the gates when a train is due, and to open them when it has passed. This double operation may even be performed at a distance (see 246, etc.); whilst, if the regulation requires the gate to be kept closed, the keeper must always be near the crossing to be ready to open whenever asked. On this account therefore has the regulation of keeping the gates open been extended to crossings, where there is even a moderate circulation on the railway.

Unless a train is expected there is no reason why a crossing should be closed, provided always that it can dispense without inconvenience with direct surveillance. Without this it would be objectionable to keep the gates open, unless that, while opening the road, they close the line, an arrangement which is now almost abandoned in France (242), and very properly so for thereby the railway is left open to any comers; there are instances of teams left to themselves having turned on to the line, instead of crossing it, and more frequently of cattle straying on to it through these openings.

In certain cases the presence of a keeper may therefore be necessary even with crossings which are but slightly used, this must not however be laid down as an absolute principle; looked at in this light the gates may be considered as forming part of the continuous fencing of the railway.

The degree of obliquity of the crossing, the greater or lesser frequency of fogs which might cause the carters to take a wrong direction, the nature of the load carried, and even the character of the surrounding inhabitants, ought also to be taken into account.

Many crossings, which during the day are open, may be closed by night without inconvenience to the cross traffic, which is then generally much less active. To keep them closed is the simpler and the surer method as far as the surveillance of the railway is concerned, and ought therefore to be preferred; they may be altogether interdicted if the night traffic is slight, but if the contrary is the case a keeper should sleep on the spot to open whenever wanted. This is clearly on the supposition, that there are night trains on the railway; but if none exist, the crossings ought to be kept open, as the circulation of the cross traffic should naturally, as soon as the other ceases, be freed from all restriction.

The following case may then occur; where the engine of the last train may be required to return back again, and which would thus take place after the hours of the regular service. This is however of such rare occurrence that the

principle cannot thereby be invalidated; but should it take place the driver of the engine must be warned to approach the crossings with great care.

239. The rules for working level crossings should in fact vary very much, as do the conditions of the localities themselves. In France all crossings are divided into five classes; the Prefect in each Department, subject to the approval of the Minister of Public Works, distributing them, while the working regulations of each come direct from the minister himself (*). As it may be of some use to make known the details of these general regulations, we shall take the Eastern of France Railway system as an example; its several lines being under different conditions.

The working of the crossing gates on this system has up to the present time been regulated by two distinct codes. Three ministerial decrees, the first dated March 21st 1853, and the other two, nearly identical, of March 17th and September 5th 1859, apply to the old system (excepting the Alsace lines), to the new system and to the Ardennes railway, which was originally conceded to a distinct company. The Alsace lines are subject to a second set of regulations, which will be noticed later on.

The two first decrees, resembling the two more recent documents which follow them, are such as to allow of the different phases of this delicate subject for regulation being followed up, and of measuring the progress therein, gradually effected in the interest of the ordinary traffic, yet without sacrificing its security.

DECREE OF MARCH 21st 1853.

The Minister of Public Works, in view of article 4 of the law of July 15th 1845 and of article 4 of the regulation of November 15th 1846, and taking into consideration the propositions of the Paris and Strasburg Railway Company, as well as the advice of the Engineer in chief " des mines ", the chief government engineer and inspector of the said line, decrees:

ARTICLE 1.

The level-crossings, established across the main line of the railway from Paris to Strasburg, and of the branch from Frouard to Sarrebrück, shall be divided into five classes.

(*) The supervision of the technical and commercial working of railways emanates directly from the minister; to allow it to be exercised by the local authorities would be to place, not legally but actually, even one single railway under as many different ruling powers as it passes through departments. The prefects are however naturally invested with the power of ordering, subject to the ministerial approbation, upon questions of purely local interest, such as those which arise between railways and other channels of communication.

ARTICLE 2.

The first class shall include all crossings on the level of all imperial or departmental roads, as well as of any parish roads where there is an exceptionally brisk circulation.

They must be watched night and day by a keeper remaining on the spot; if much used the gates shall remain open regularly, to be closed by the keeper when a train is in sight or is due. A certain length of line may also be looked after by the keeper, but conformably to article 7 which follows.

ARTICLE 3.

The second class shall comprehend all parish and township roads, where there is a keeper's house near to the level-crossing; the place of the keeper may during the day be filled by his wife. The gates shall be locked during the day, to be opened whenever required by the public, unless a train is in sight or expected; during the night they must also remain closed, and the keeper must get up and open them whenever asked; nevertheless the Company may always be compelled, if the exigencies of the traffic require it, to place a special night watch to attend to them at this time.

ARTICLE 4.

In the third class shall be included the crossings of all parish and township roads, that have no keeper's house in their vicinity; these must as a rule remain closed, and it is the duty of the day or night man in charge of the section of line they are upon to open the gates; the length of the section shall be regulated by the importance of the traffic on the crossings, and by the nature of the ground the line passes through on each side of them. If no traffic takes place during the night or at certain times of the year, the company may be authorized to close the crossings during a portion of the day or year.

ARTICLE 5.

The crossings, granted to private individuals on condition of their working them, shall form the fourth class. The gates must be opened and closed by the persons to whom they are granted, under the supervision of the railway watchman of the length they are on, or by this man himself. These crossings may in case of necessity be closed either during the night, or at certain periods of the year, or at the time when fast trains are due; in which case they must be locked by the company's agent.

ARTICLE 6.

Finally, in the fifth class are included all crossings for foot passengers. These must have turnstiles, or other appliances suitable to exclude the passage upon the line of cattle; they must be placed as much as possible alongside of carriage crossings, and be watched over by the keepers of those crossings.

ARTICLE 7.

The level-crossings shall be distributed according to the foregoing classification in each department by a decree of the prefect, based upon the propositions of the company and upon the advice of the chief government inspecting engineer. This decree shall prescribe all the measures necessary to ensure regularity and security in working the crossing gates, it shall also enjoin the mode of lighting the crossings.

The decrees of the prefects of the several departments traversed, issued in conformity with these present, shall be submitted for our approval.

The system of keeping crossing gates open as a rule appears in this decree only in article 2, and then but timidly so to speak. It is applied merely to level-crossings of the first class, with a keeper always on the spot; and even then only to those of an exceptional traffic in this class, where in all must by its definition necessarily possess a considerable one.

The decree of September 5th 1859 made, as will be seen, a great step in advance. By article 2, all first class crossings remain open regularly, and article 8 initiates a new order of things in allowing the extension, though exceptionally it is true and on lines with few trains running, of the permission to keep open during the day to crossings of the second and third classes, which actually have no keeper stationary on the spot.

DECREE OF SEPTEMBER 5th 1859.

The Minister Secretary of State of the Department of Agriculture, Commerce, and Public Works, in view of Article 4 of the law of July 15th 1845 and of article 4 of the regulation of November 15th 1846, and taking into consideration the propositions of the Eastern Railway Company, as well as the advice of the Engineer in chief " des mines ", the chief government engineer and inspector of the said line, decrees :

ARTICLE 1.

The level-crossings established across the lines and branches composing the second portion of the system of the Eastern Railway are divided into five classes.

ARTICLE 2.

The first class includes the level-crossings of imperial and departmental, and likewise of those parish roads, which have an exceptional circulation upon them.

They must be watched day and night by a keeper remaining on the spot, who may also be entrusted with the supervision of a section of the line, the limits of which must be fixed conformably to Article 10 which follows. This keeper must reside in a house adjoining the level-crossing.

During the day the working of the crossing gates may be entrusted to a woman.

The gates of these crossings are to remain open regularly, to be closed by the keeper only when a train is due or is in sight.

ARTICLE 3.

Parish or township roads having an ordinary amount of traffic are comprised in the second class of level crossings. The keepers' houses must be placed conveniently to the crossings.

The working of the gates is entrusted, during the day to the wife of the keeper, who may himself superintend a section of the line or be attached to the maintenance staff, and during the night to the resident watchman, who must get up whenever demanded by the public.

The gates must be closed day and night, but opened when required by the public, unless a train is in sight or expected. During the night however the company may be compelled, if the requirements of the traffic require it, to place a special watchman to work these gates; and, if there is no road traffic, the company may close them altogether.

ARTICLE 4.

The third class includes all crossings of parish and turnpike roads having but little traffic. These level crossings must remain regularly closed, and it is the duty of the day or night man in charge of the section of line they are upon to open and close the gates; the length of the section shall be regulated by the importance of the traffic on the crossing, and by the nature of the ground the line passes through on each side of it.

Wherever a keeper's house is built adjoining to one of these crossings, the same regulations shall be in force with it as with those of the second class.

If no traffic takes place during the night, or at certain times of the year, the company may be authorized to close the crossings during a portion of the day or year.

ARTICLE 5.

Whenever crossings of the second or third class shall be sufficiently close to one another, the company may be authorized to entrust their working to one single keeper.

ARTICLE 6.

Level-crossings granted to private individuals, whether for carriages or for foot passengers, on condition of their being worked by them, constitute the fourth class.

The gates are to be locked by the persons to whom they are granted, and worked by them on their own responsibility.

All transit is forbidden on these crossings during the night, and when fast trains are due. Whenever any extra fast trains are expected crossings of this class may be temporarily closed by the company's agent, for a period sufficient to ensure the security of those trains.

ARTICLE 7.

The fifth class comprehends all public crossings for foot passengers. They must be provided with wickets or other appliances, suitable to prevent the passage of cattle upon the line.

ARTICLE 8.

On those sections of a line, where the number of trains is not such as to justify the constant closing of the gates of crossings of the second or third class, these may be left open during the day, except when a train is in sight or is due.

ARTICLE 9.

All level-crossings of the first class must at night be lighted by two lamps. First and second class crossings, which are not intercepted, must have one light burning all night.

Those on which night traffic is forbidden need not be lighted during the prohibited time.

Crossings of the fourth and fifth class need not be lighted.

ARTICLE 10.

The level-crossings shall be distributed according to the foregoing classification in each department by a decree of the prefect, based upon the propositions of the company and upon the advice of the chief government inspecting engineer.

This decree shall decide upon the length to be assigned to keepers of first class crossings, upon the classification of those crossings to which are applicable the special arrangements mentioned in articles 3, 4, 5, and 8, and upon the portion of them to be applied to each crossing, where the limit of these arrangements is not fixed by these present.

The several decrees, issued for this purpose by the prefects of the departments traversed, shall be submitted for our approval.

ARTICLE 11.

The arrangements of this present decree shall be applicable to all lines of the Eastern Railway system; excepting those from Paris to Strasburg and Frouard to Sarrebrück, from Strasburg to Bale, from Epernay to Rheims, from Lutterbach to Thann, and from Vendenheim to Wissemburg, which will continue to be regulated by the administrative decisions already promulgated.

The existing decisions, relating to the parts of the Eastern Railway to which the arrangements of this present apply, are hereby repealed.

The regulations maintained in force for the lines mentioned in article 11 form, or the four last, the exceptional rule already spoken of; the chief character

of which is that all crossings are kept open regularly day and night, and only closed when a train is in sight or expected. This arrangement, more convenient for the inhabitants and more economical for the company, has up to this presented no inconveniences; it has even, after, a lengthened application on the lines from Strasburg to Bale and to Wissemburg, been extended to several which have been opened since the decree of September 5th 1859.

Progress in this matter must no doubt be made with due caution; as, for example, a regulation, though good in Alsace, might be very bad in the neighbourhood of Paris, where the lines have many fast trains running upon them and pass through a population totally different in character from the first named; a circumstance which ought to be taken into consideration without abandoning on this account the endeavour slowly to reform their unruly ways and to introduce in their stead habits of consideration and respect for regulations, of which the inhabitants themselves would be the first to reap the benefit.

240. One must however acknowledge, that, even if comparative experience is useful, the application of two sets of rules entirely distinct to different districts of one railway, though placed under conditions which practically vary but little, cannot be a normal and definitive state of things. It is manifestly desirable, that on one railway system one single code should be in force, though sufficiently general, and pliable enough in its details, to include all those cases, which constitute the varying conditions between one district and another. It is also only natural to make a distinction between lines where the circulation is great, and security requires a stringent regulation, and those on which the trains are few, and where the stringency demanded on the former may be relaxed.

The Eastern of France Railway company have with this object studied and presented the following scheme; a proposition which has taken a marked place in the examination of a question, the importance of which justified some tardiness in its development.

DRAUGHT OF DECREE

FOR REGULATING THE MANAGEMENT OF THE GATES OF LEVEL-CROSSINGS.

ARTICLE 1.

The level-crossings established across the Eastern Railway are divided into five classes.

ARTICLE 2.

The first class comprises the l. c. of imperial and departmental roads, and of those parish ones which present an exceptional amount of traffic.

The gates of these crossings are to remain open regularly, to be closed only when a train is in sight or expected. Their opening and closing is to be performed night and day by a keeper, who should be on the l. c. during the whole time it remains closed. This duty may be entrusted to a woman.

ARTICLE 3.

In the second class are included the l. c. of roads having an ordinary amount of traffic.

On lines with a great number of trains running, these l. c. are regularly closed night and day, and opened when demanded by the public; where however the number of trains is moderate or even small, the gates remain open regularly during the day that is from sunrise to sunset, but during the night they are closed, to be opened at the request of passers by (see article 7).

ARTICLE 4.

In the third class are placed the l. c. of roads, the traffic on which is but slight.

They are closed regularly day and night, and opened whenever required by the public.

ARTICLE 5.

The l. c., whether for carriages or for foot passengers, granted to private individuals on condition of their being worked by them, form the fourth class.

Their gates must be locked by the proprietors, and worked by them on their own responsibility.

ARTICLE 6.

The fifth class includes the public l. c. for foot passengers.

The wickets, whether away from or contiguous to a l. c. of the three first classes, are never locked, and are to be managed by the passers by.

ARTICLE 7.

On lines having but a moderate or a slight circulation, the company, without previous authorization, may leave crossings of the second and third class open, in proportion to the wants of the local traffic, beyond the limits specified in articles 3 and 4.

These extensions of the period of opening may be rendered obligatory by the authority of the prefect, on the advice of the government inspecting engineer in chief, when the measures taken by the company do not sufficiently satisfy the requirements of the road traffic.

In all cases, on lines where there is no night service, the gates are to remain open from the time the last train at night has passed till the first morning one is due.

ARTICLE 8.

At those points where there is no road traffic during the night or at stated periods of the year, certain l. c. specially mentioned may be closed during a portion of the night or year.

ARTICLE 9.

When application is made to open a gate, the keeper must first satisfy himself, that there is time to cross the line before the arrival of a train; in which case he opens the gates, commencing with the outlet one, and closes them again at once.

At l. c. with gates worked from a distance (246), application to open is made by means of a bell. The keeper on his part, before closing the gates, must ring several times as a warning.

ARTICLE 10.

The gates of l. c., which are open regularly, ought to be closed five minutes before the time indicated for the passage of regular or extra trains; when passed, the gates are at once reopened. During the time they are thus closed they may, if asked for, be opened, subject to the conditions and in accordance with the prescriptions of the foregoing article.

When a l. c., near to a station, shall be so situated as to be liable to be interrupted for more than ten minutes consecutively by trains, either stationary or while shunting, the prefect shall fix, if it be necessary, on the proposition of the chief government inspecting engineer and of the company agreed, the maximum duration of the interruption for the crossing.

ARTICLE 11.

During that part of the night when trains are running, l. c. of the first class shall be lighted by two lamps; while those of the second class, and all that are worked from a distance, are to have one only.

ARTICLE 12.

In cases of dense fog the service of the l. c. shall during the day be subject to the same rules as during the night.

ARTICLE 13.

The distribution of the l. c. into each of the above mentioned classes and the application of the arrangements of article 8 of the present decree shall be determined, on the proposition of the company, by decrees of the prefects, which shall be subject to the approval of the minister.

ARTICLE 14.

The prefects of the departments traversed by the Eastern Railway, and the chief

government inspecting engineer, are charged with the execution of the present decree.

DRAUGHT OF DEGREE OF CLASSIFICATION.

ARTICLE 1.

The line from____________is included among the railways of the____________ circulation.

Its level-crossings are classified as follows.

NUMBER IN ORDER.	DESCRIPTION and number in order by parish.	MILEAGE.	CLASS.	CLASSIFICATION of roads crossed.	KIND of gates.	OBSERVATIONS.

ARTICLE 2.

Conformably with article 8 of the preceding decree, traffic may be entirely prohibited during the hours below stated at the following level-crossings.

NUMBER IN ORDER.	DESCRIPTION and number in order by parish.	MILEAGE.	INTERVAL OF TIME during which the gates may be kept constantly closed each day.

ARTICLE 3.

Traffic may be completely forbidden, except during sowing and harvest times, or whilst the felled wood is being cleared away, at the times designated for such purpose by the several mayors, or by the administration of Woods and Forests, upon the following level-crossings.

(Here follows their enumeration.)

ARTICLE 4.

The chief government inspecting engineer is charged with the execution of this present decree.

By article 3 of this proposal, the Eastern Railway company tends to initiate for the greater part of its system an important innovation, in furthering freedom of circulation on a tolerably large class of crossings; while on the contrary this article places a restriction upon certain lines, as for example the Alsace ones, which have for some time back possessed a more extended regulation, that allowed all gates without distinction of class to remain open night and day. Article 7 however reserves all acquired rights, and permits of the same regulation being extended in a greater or less degree to other lines.

The advantages of this regulation are so appreciated by the inhabitants, that the general council of the Department "du Bas-Rhin" has lately asked for its application generally to that portion of the Paris and Strasburg line comprised within it. This was straining it too far; for, on a line with so great and fast a circulation, security would have been compromised by the gates remaining permanently open, or at least it would have entailed a keeper always on the spot; in fact it would have left but one class of crossings, the first.

Article 9 recapitulates, in the same terms as formerly (235), the injunction to crossing keepers to make themselves certain "that the line can be crossed before the arrival of a train"; it is needless to add that, if the nature of the country is such that the keeper cannot himself ascertain the fact, special measures should be taken to effect this (237). If this circumstance had been merely mentioned among the regulations, this draught sketch, which is at present open to criticism, would have been improved; its silence on this point was explainable at a time when on some level-crossings warning or distance signals had not yet been applied. In it therefore there still is something understood, but happily however for very rare cases.

241. *New regulations of the Paris and the Mediterranean Railway.*— This company presented on its part a draught of regulations, which received the ministerial approbation, and was decreed on December 31st 1866; it is given in full farther on, as being the most recent on the subject.

On many points it is drawn up nearly as is that of the Eastern Railway, though differing from it in many essential arrangements. Thus it departs from the principle, that at each level-crossing there should be a keeper's house. This ought to be the case on lines with great traffic and high speeds, where level-crossings can only be permitted with great reserve, and hence are few in number; to extend however the same principle to secondary lines, in themselves but little remunerative, would be at once to burden their cost with considerable expenses under the head of deviation of roads, and to impose upon

the surrounding population extra distances to be travelled over, not at all necessary for the maintenance of proper security.

On these kind of lines one could never think of requiring a resident keeper upon each crossing, occurring, as they sometimes do, two, three and even more within one mile. The regulation of the Mediterranean line on the other hand curtails the usual time for keeping gates open, allowing it only during the day on crossings of the first class, and on those of the second " situate on lines with only a moderate or a slight circulation of trains ". It also arranges beforehand for the application of gates worked from a distance.

DECREE OF DECEMBER 31st 1866.

ARTICLE 1.

The level-crossings established for the passage of the Paris Lyon and the Mediterranean Railway are divided into five classes.

ARTICLE 2.

In the first class are included all level-crossings for vehicles, opened on an average more than one hundred times in the twenty four hours.

During the day the gates of these level-crossings should remain regularly open, to be closed when a train is expected or in sight; during the night they are regularly closed. Their working is to be performed both day and night by keepers, who ought always to be close to the crossings; during the day only may this duty be entrusted to women.

ARTICLE 3.

The second class comprises those level-crossings for vehicles, which are opened on an average between fifty and one hundred times during the twenty four hours.

During the day, 1st on lines with a very great train circulation, the gates are to be regularly closed, and to be opened on the application of the passers by; 2nd on lines having but a moderate or a slight number of trains upon them, the gates are to be regularly open.

During the night the gates are on all lines to remain closed as a rule; a man residing in a house adjoining the level-crossing must however answer the demand of all passers to open the gates.

ARTICLE 4.

In the third class are placed the level-crossings for vehicles, which are opened on an average less than fifty times during the twenty four hours.

They remain closed regularly day and night, to be opened on the application of the passers by a keeper residing in a house contiguous to the level-crossing.

ARTICLE 5.

The level-crossings, whether for vehicles or for foot passengers, granted to private individuals on condition of their being worked by them, form the fourth class.

The gates are to be kept locked by their owners, and worked by them on their own responsibility.

ARTICLE 6.

The fifth class includes all public level-crossings for foot passengers, whether isolated or alongside of those for vehicles. The crossings must be closed by small gates or wickets, to be opened by the passers at their own risk and peril, and which are to be self closing by their own weight.

ARTICLE 7.

On lines where there is no night service the gates of level-crossings of the first, second, and third classes shall remain open, excepting the necessities of the service, between the last train at night and the first one in the morning.

ARTICLE 8.

At points where the traffic is null during a portion of the day or night, or at certain periods of the year, certain level-crossings specially mentioned may be kept constantly closed during a part of the day or of the year.

ARTICLE 9.

When a crossing gate is asked to be opened, the keeper, before acceding to the request, should make certain, that there is time to get across the line before the arrival of a train; in which case he opens the gates, commencing with the exit one, and closes them again immediately.

The keeper ought to refuse to open, if the train is in sight at a distance of less than 1 ¼ miles, or if it is announced, either by the sounding of a horn by a neighbouring keeper, or by any other means.

At level-crossings closed by gates worked from a distance, a request to open must be made by means of a bell; and on his part the keeper, before closing it, ought to give several strokes on the bell as a warning.

ARTICLE 10.

The gates of level-crossings, which are kept regularly open, ought to be closed five minutes before the time appointed for the passing of regular or of extra trains; they are to be reopened immediately after they are passed. During the time they are so closed they may be opened, if demanded, subject to and conformably with the prescriptions contained in the preceding article.

When a level crossing, near to a station, is so situated as to be intercepted for more than ten minutes consecutively by a train, whether halted or while shunting, the prefect shall fix, if there be any necessity for so doing, on the proposition of the

chief government engineer and the company agreed, the maximum duration of the interruption of the crossing.

ARTICLE 11.

During the whole of that portion of the night when the trains are in motion, and so long as the gates remain closed, level-crossings of the first class must be lit with two lights. Those of the second class require only one. While those of the other classes are not lit up at all, unless under special orders from the superior administration.

ARTICLE 12.

The division of the level-crossings into each of the classes hereinbefore named, and the application of the arrangements of article 8 of this present, shall be regulated, on the proposition of the company, by decrees of the prefects, which shall be submitted for the ministerial approbation.

Paris. December 31st 1866.

These regulations appear to have been studied by the company itself, principally with regard to their main lines. Such no doubt ought to be the case, since the regulations consist of absolute prescriptions; it might however happen, that these rules, sufficing merely for the main lines, might be too stringent for the secondary ones, and that not only as regards the economical interests of the company, but also respecting the restraint imposed upon the cross road traffic. It is this double difficulty, which the proposition of the Eastern Railway has endeavoured to avoid.

It essays to define clearly the obligations of the company, and the conditions of opening and of closing each class of level-crossing; but as to the means of carrying them out, it avoids tying down the company's hands in the matter. Thus, the question of crossing-keeper's houses is not raised, though frequently the necessity for them arises from the very arrangements of the proposition; such as rendering obligatory the presence of a keeper upon crossings of the first class during the whole time they are closed (art. 2), and the permission to entrust the duty to women, which implies the existence of a keeper's house. If therefore the *word* is not actually in the proposition, the *fact* is really included there; while it would still remain with the company to judge of those cases, where it ought to be applied in order to fulfil its own obligations.

Instead of requiring, as does the regulation of the Mediterranean line, the constant presence of a keeper *near to* crossings of the first class, the proposition of the Eastern railway speaks only of the periods during which they are closed; it then requires his presence not merely *near to* but actually *upon* the

crossing. This in fact being necessary to ensure, in case of a train being late, the application of article 9, if there is any call for it, without loss of time, which may be precious.

Briefly we may say, it is a question of assuring public security, while restraining as little as possible the cross traffic, and yet placing as few hindrances as need be in the way of the circulation of the trains; and, since the conditions of the problem differ singularly between one point and another, it is likewise necessary that its solution should vary also. But more than this, not only is it between one crossing and another, but often with the same one, from one period to another, that these conditions are modified. Thus, during whole months a very feeble traffic may exist, which sometimes springs during others into a very active and continuous one. To apply always to these crossings the regulation of remaining constantly open would be to burden the company with the working of gates absolutely useless during the periods of stagnation in the road traffic; while to insist upon regularly closing them, or even upon the mixed arrangement of the second class (240, Art. 3 of the proposition of the Eastern line, and art. 3 of the Mediterranean regulations), that is to say, open during the day and closed at night, would be to impose a serious check upon the road traffic during its times of activity. These crossings require a rule as variable as are their own conditions; regularly closed during periods of stagnation, and similarly open while an active traffic prevails. That the arrangement should be thus adaptable to elements which are so variable is but logical; and this can only be realized by a rule, which shall be absolute in its principles, yet flexible in its application.

§ XIII. — Different kinds of gates.

242. Gates may be divided into, 1st bar gates, 2nd revolving ones, and 3rd those which roll in their own plane.

Bar gates may be, either sliding, or turning on a vertical axis, or round a horizontal one.

The last named of these forms is applied on the railways from Verona to Venice and to Botzen. The axis of the gate is a pin set in a post; and it is balanced by a counter weight placed underneath for stability, often consisting of a large stone fastened to the short arm of the lever. A slight impulsion is sufficient to work these bars; only they require a considerable space for working in, and on this account the bar gates which balance vertically are preferable.

Revolving gates are the most in use. They are either in two leaves, or in a single one; if the moderate width of opening allows of it, the latter form is

the better, as to work it but one operation has to be performed on either side of the line.

In general these gates are made to open towards the inside of the line; their hinge posts ought to be sufficiently wide apart to allow of the leaves; when open, being at least 5 feet from the nearest rail. The keeper will then have no necessity, while opening the gates, to cause any vehicle to back, which has advanced too close; nor, in order to close them, to make another which arrived rather too late do the same.

The gates, which open outwards from the line, have on the other hand the marked advantage of reducing the breadth of the crossing; nor are they exposed, as are the others, when badly closed, to yield to the pressure of cattle against them. There seems therefore no reason for proscribing this kind of gates, to which some companies give the preference.

When the gates close the line, and open the road, they may become a source of danger to their keepers, who sometimes rush to work them rather dilatorily in front of a coming train. Those, though few in number, which still exist are frequently broken; and their fragments are apt to wound the engine driver and the stoker. Still, where cattle abound, they are to be preferred; especially if the level crossings remain regularly open.

243. Without stopping to describe the details of construction of revolving gates, we shall just mention the arrangement of two economical forms thereof, one single, the other double, in use on the line from Dieuze to Avricourt on the Eastern of France (Pl. XI, figs 27 to 33). Each leaf is composed of a bar L, of the upright pivot post P, and of a tie-bar *c*. The open space below the bar is divided by a lower bar *l*, hung by two short chains, and resting against the post and the tie-bar. In the double leaved gate, each half has a triangular iron frame *t*, *t*, which when the gate is closed fastens into a cast socket *s* (fig. 32), set in the ground, and thus backing up the whole; it also affords, by means of its side *mn*, become almost vertical, a third point of support for the bottom bar (figs 27 and 30). Whilst the gate is being moved, this triangle is hung up to a hook *p* (figs 27 and 33), fixed on the bar. The two leaves are also sometimes joined by a bolt.

In England the two halves on either side of the line are often connected together by chains under the ground; so that the gate keeper can work them both by one operation without having to cross the line. The same arrangement has been proposed in Germany, but it does not appear to have been carried out.

244. *Rolling gates.* — This form is resorted to when, in consequence of limited space, revolving gates are inapplicable.

The use of iron as the material for this kind of gates, which ought to be light yet rigid, naturally suggests itself.

Figures 34 to 37 of Plate XI represent one of these trellis gates on the Orleans line. The bars being angle irons fulfil the two conditions of lightness and of rigidity. Though the rollers R, R, which carry them, are of large diameter, the working of these gates is harder than that of revolving ones. This is a serious inconvenience, especially as they are generally worked by women.

These rolling gates are nevertheless almost exclusively adopted on the lines of the central portion of the Orleans system; they are however very light. Bar gates, worked from a distance, might with advantage have been applied on many of these lines; which serve but thinly populated districts, and where probably the traffic is but moderate.

On the Southern of France, the top and bottom bars are connected by a very open meshed trellis, the channel-iron bars of which cross one another only at the centre, where they clip between them a flat bar of the same thickness as the top and bottom ones. The lower half of the gate has a closer trellis, with flat bars carried down to the ground; thus forming an efficient protection against smaller animals. This arrangement is favourable to the lightness of the rolling structure, as well as to its stability; on account of the centre of gravity being low down.

245. Rolling gates in fact have a tendency to bend and to buckle; the ends of the axle pins of the rollers then rub against the edges of the groove, and the gate becomes hard to work. In some cases, as in the station at Schaffhousen, in order to afford greater stability two sets of rollers are fixed on, working in two parallel grooves. On the line from Sieg to Ruhr, each trellis-gate is supported, at one end by two wheels with flat tyres, rolling on flagstones, and at the other, where stands the fixed guiding-trellis, on a single roller having its tyre hollowed out in the middle.

246. *Bar gates worked from a distance.* — These gates, so economical in themselves, are often not considered to form a sufficient enclosure. In France, for instance, they have until lately been prohibited in principle, and only tolerated at certain points. It appears nevertheless, that the enclosure round a level-crossing ought to afford protection to the railway, which it only does when it renders impossible the introduction of cattle upon the line, the very presence of which becomes a source of danger to the trains. Another requirement, though a lesser one, from the method of construction of gates, is the na-

tural consequence of the extension of the regulation for keeping them open.

Bar gates have the advantage, often an important one, of being able to be worked from a distance.

This arrangement, long in use in the north of Germany, has successively been extended throughout the whole of that country. At first a keeper was attached to each of the crossings, often very close together; this exaggeration was too manifest not to endeavour to remedy it by entrusting two and even three crossings to one keeper. Hence their being worked from a distance.

When merely a balance motion is sought to be imparted to the bar, this is easily produced from a far off in the same way that distance signals are worked at a mile, or even more, from their levers.

On the Baden Railway one keeper has ordinarily to look after three level crossings. The middle one, the most frequented if possible, is closed by a sliding bar worked directly by the keeper; those on either side have balanced lever-bars worked from a distance.

Thus on the Hanoverian lines many hundred crossing keepers have been dispensed with; while the application of this method of transmission was limited to those crossings only, which were quite visible by the keeper from his post.

On the Cologne and Minden line the crossing keepers are forbidden to work the distance gates, whenever they are obscured by fog or any other cause; they then ought personally to visit each of them.

The Dresden meeting fixed 600 yards as the maximum distance between the working post and the crossing (*).

247. *Applications in France.* — The Eastern of France Railway have since 1859 tried these distance gates on the line from Strasburg to Bale, with complete success. The company is now developing their application, though always confining them, it is hardly necessary to add, to lines and cross roads of secondary importance, and to gates which are kept open during the day.

This method of working from a distance is in force at present, with the authorization of the minister of Public Works, on the lines from Strasburg to Bale, Wissemburg, Barr, Mutzig and Wasselonne; from Mulhousen to Wesserling; from Schlestadt to Sainte-Marie-aux-Mines; from Haguenau to Niederbronn; from Epinal to Gray and to Remiremont; from Luneville to Saint-Dié; from

(*) " Vereinbarungen, etc. (Sicherheits-Anordnungen) " art. 7.

Avricourt to Dieuze; from Rheims to Chalons; and even in the environs of Paris on the line from Gretz to Coulommiers (Pl. XII, figs. 1 to 9).

The surrounding population find them to be to their advantage, as does the railway also. Working from a distance in fact reduces the time during which the gates are closed, as the keeper has no longer to traverse several hundred yards to close and then to open them, before and after the passing of each train. And respecting their economy; as the idea no longer prevails, which existed for so long, that railway companies were rich enough to overlook details, any reduction of expense ought to be eagerly accepted, which affects neither the safety nor the regularity of the trains. Besides under the arrangement of guaranteeing the interest, applied on the new railway systems, the state, or in other words the public, is more interested than the companies themselves in keeping down the working expenses.

The Eastern Railway C° has not confined itself to imitating purely and simply the forms in use in Germany; it has introduced therein marked improvements, and has applied the principle to distances greater than have been attained on the other side of the Rhine, while also working round curves in a quick and easy manner. One of the level-crossings on the line from Luneville to Saint-Dié, that of Etival N° 3, is more than 900 yards from its working post at N° 2, crossing.

In Germany the keeper, when at his working post, ought distinctly to see the gates. This condition has been fulfilled for the greater number of those on the Eastern of France; there are however some exceptions, as for instance that of Etival N° 3. This crossing presents some danger; the bar-gate being too close to the outside rail to allow of a vehicle, which might be shut on to the line by the bars being let down, being saved by placing itself longitudinally thereto.

To allow of this being done the gates ought to be placed about 12 feet from the nearest rail; whereby the length of the crossing and the time occupied in traversing it would be increased, so much so perhaps that the inconvenience might more than compensate for the advantage of the method adopted.

Besides, even if the crossings are visible to the keeper during the day, they are only very imperfectly so during the night; it is true that they are lit up, but this is more to point out their position to passers by; it is not sufficient completely to inform the keeper of what is taking place there, more especially as vehicles are often without lamps.

The working of the distance gates must in all cases be regulated, so that the public security be guaranteed, although the keeper can only see the crossing imperfectly or even not at all.

The guarantee consists in a double communication by means of bells, between the keeper and the crossing, and vice versâ for those who wish to pass over it.

Figures 21 to 30 of Plate XII represent the form adopted by the Eastern of France, after having tried the arrangements shown in figs. 10 to 13, and 14 to 20. The counterweight, more economical than the cast box A of the method indicated in figs. 14 to 20, is composed of two rail-ends ϖ, ϖ, (figs. 23 and 24), fixed across the end of the bar, which is guided at the other by the wide forked mouth f, f; the bell handle m, is placed close to the windlass.

The plan shown in figure 22 explains the arrangement of the pull-ropes, so that the keeper can work both gates at once.

The service thereof is arranged in the following manner.

During the day the gates worked from a distance are kept regularly open, and closed only at the time of the passing of the trains; before closing the gates the keeper as a warning gives several strokes on the bell, and takes care to allow sufficient time to elapse before closing the gates to enable the crossing to be left free.

During the night, or in case of a dense fog, the gates are kept regularly closed, and only opened when demanded by the passers. This is done by means of a bell placed close to the keeper's post, and having a handle on each side of the level crossing.

If a carter, neglecting the warning signal, the meaning of which ought to be marked up very legibly, enters upon the crossing whilst the lever gates are being let down, he has only to ring the bell to ask for their being reopened. As the gate ought to be closed several minutes before the train is due, the keeper always has time to do this, and then to close it again.

218. Sliding-bar gates were tried on the Coulommiers line (Pl. XII, figs. 1 to 7); the wire f, f, serving to open them, while they were closed by the return motion of the windlass by means of the wire f', f', passing over the return pulley P (fig. 3). The sliding-bar travels upon the fixed one M, M, on the rollers ρ, ρ, to reduce the friction.

The warning signal preceding the closing of the gate is given by the bar itself, from the very commencement of its motion; its upper side being furnished with several small strikers h, h, h, which successively come in contact with the hammer of the bell T (figs. 3, 6, and 7). To render the signal effective the keeper ought, after having caused the bar to travel a short distance, to stop it for several seconds, so that any vehicle on the crossing may have time to get off it.

Whilst the bar is being drawn back, the rounded end *l* of the hammer slips up to allow the strikers to pass, without displacing the hammer itself; thus whilst the gate is opening the bell does not sound.

The cost of these sliding-bar gates is rather more than that of the lever-bar ones (£ 30 per crossing, including transmission to 760 yards off, against £ 24), they work however equally well; but with the former kind each side of the line must be worked separately, whilst with the latter the two bars are raised or lowered at the same time. The latter form is therefore preferable.

249. This form of enclosure, in its ordinary form, has been sometimes objected to, as being impossible to open from the crossing itself; but it is precisely what is wanted, and rightly so. This impossibility is a general guarantee, and an inconvenience only where a team might be shut in between the gates; in which case the wire rope would have to be broken before the bar could be raised.

It would however be easy to render possible the immediate working of the bar, if thought useful to do so.

It needs merely to transfer the point of fastening of the cord from one side of the axis of rotation of the bar to the other (Pl. XI, fig. 43); or else, as has been done under the direction of Mr Kirchweger on the Berg and La Marche Railway, to render the counterweight P independent of the lever-bar, and moveable round a special axis O (Pl. XI, fig. 44). To close the gate, the cord becoming taut raises the counterweight, and the lever-bar follows this movement of itself; while opening, the counterweight set free by the cord carries with it the lever-bar. This last may if needed be raised by the carter, but he will find it difficult to guide his team and at the same time keep the bar raised. By this arrangement the enclosure in fact becomes simply a warning and no longer an obstacle, unless it is to cattle without any one to look after them.

Another objection raised against the ordinary arrangement is, that, if the cord breaks, the gate though closed opens of itself. The opposite takes place with the disposition shown in figure 43. The objection is however without weight, as it is easy to make the wire rope sufficiently strong to prevent its ever breaking.

250. A German engineer, Mr Overbeck, has introduced some ingenious modifications in these lever-bar gates; they have however the effect of at once altering their essential character, of simplicity, and the guarantees they ought to offer.

As they may nevertheless be used in certain particular cases, it will be well to describe them (Pl. XI, figs. 39, to 42).

Their object is, 1st to render the direct working of the bar easy and convenient, whilst warning the keeper of what takes place; 2nd to produce by the action of the winch itself that warning signal, which a careless keeper might forget to give previous to lowering the gates.

The counterweight P, applied to the smaller arm of the lever, keeps it in every position in equilibrium round its axis of rotation, which passes through its centre of gravity. The working rope is double, one to open the gate, the other to close it; the cord to the bell is done away with altogether.

The upright post *p* has on it two pullies D, *d* (fig. 41), of unequal diameters, keyed on to the same axle, and independent of each other as long as the spur *e* on the smaller one is not in contact with the pin *h* fixed in the larger.

Their jaws are grooved spirally, on the larger pulley are coiled the chains of the two working ropes, and on the smaller one the chains *r*, *r'* (fig. 39), fastened to the two arms of the lever-bar. The two chains on each pulley are coiled in opposite directions; it is the same with the two chains at the other end, attached to the two transmission ropes, and rolled on the working winch.

Let us suppose the gate to be open; the pin *h* of the large pulley is then at the highest point of its course, and the spur *e* of the small one immediately behind it.

The keeper raises the stop *c* of his winch (fig. 42), and turns in the direction for closing the gate. The large pulley turns the same way, and the prolongation *h'* (fig. 41), of its axle-pin strikes a lever which sets the bell in motion.

So far the small pulley has remained still: it is not carried round by the movement of the large one until the latter, after one turn round, urges it on by the contact of its pin with the spur of the former. The lever-bar does not however commence to descend at this moment; as the chain *r'*, being loose when the bar is raised, requires about a half turn to make it taut. The bell rings three times before the gate is closed.

If the gate is raised directly, by hand, it retains the position given to it, and the carter can give his free attention to guiding his team. The movement however of the bar has caused the small pulley to turn, and its spur *e* on striking the pin *h* of the large one has almost immediately caused its rotation, and consequently also that of the winch by means of the working rope. The clicking, caused by the stop *c* upon the teeth of the winch wheel, warns, and at the same informs, the keeper of what is taking place.

This system may be suitable for lines, where it does not appear admissible to keep the gates constantly open. The railway being closed against cattle

which are left to themselves, without hindrance to the cross traffic on the road; but the inconvenience is precisely that this exceeding liberty may be abused at the risk and peril of the cross traffic, as well as to that of the trains.

The Dresden meeting recommends (*), that these distance gates should be arranged so that their keeper may be able to open and close them by hand, and that the driver of a team, shut in upon the line, may be able to let himself out. This recommendation has however been hardly followed up to the present, nor is it probable that it will be so generally.

251. *Distance gates with a lower bar.*— On the Eastern of France Railway, the only one in that country which has applied this working from a distance, the bar of the gate is 3'·6" above the ground. The government turned its attention therefore to the dangers which might arise from this height, sufficient to allow of small animals getting upon the line. To reduce it would have necessitated altering all the existing gates, already numerous; the counterweights would also have had to have been augmented to compensate for the diminution in their arm of the lever. But the most serious result would have been, that, while rendering the passage under the bar more difficult or impossible, that over it would have become much more easy; horses especially could get over it very readily.

These various objections may all however be reconciled by the addition of a lower bar, similar to that in the hinge gates on the line from Dieuze to Avricourt (Pl. XI, fig. 27). When the lever-bar is raised, the lower one lies against it, and, when the gate is closed, the lower bar assumes of itself its normal position, 1'8" below the upper one.

Sometimes chains (Pl. XII, figs 15 and 16) have been used to hang it by, or else wooden or iron bars, jointed at both ends (figs 23 and 29); the latter method is the preferable, as this lower bar if hung thus rigidly is less easy to raise by itself. It is made of fir, as lightness is necessary to enable it to work easily; its scantling may be reduced to 2" by $\frac{3}{4}$", which appears sufficient, the prop fences near level crossings possessing even less resistance.

252. Companies, as well as the government, cannot consent except with a very proper reserve to establishing private crossings (of the 4th class) on lines with a brisk circulation; this consent becomes more easy in proportion as the traffic is less. These crossings, which their owners use at their risk and peril and on their own responsibility, ought however to be kept locked;

(*) " Vereinbarungen, etc. (Sicherheits-Anordnungen, art. 10). "

this condition is not always fulfilled, and the security of the trains is possibly thereby compromised. Sometimes working from a distance may reconcile this difficulty; as occurred in a case on the line from Luneville to Saint-Dié. A landowner, to whom a crossing had been granted, did not fulfil his obligation of keeping his gate closed. On being taxed with being backward in complying with the conditions of the concession, he alleged the difficulties it presented, the importance of the crossing, and finally ended by asking the company to place it under the same conditions as public crossings, charging him with its working expenses.

With the ordinary system this demand would have been met by a formal refusal. To depute a special keeper to the crossing in question could not be thought of, and to have entrusted the direct working of its gates to the woman in charge of the nearest level crossing, one third of a mile away, would hardly have satisfied the proprietor himself. Working from a distance however allowed the company to accede to his demand without incurring a great expense; while at the same time it met his request to raise, as it did in fact, the crossing from the 4th to the 3rd class.

258. The application of gates worked from a distance may still require some improvements in detail, which will be suggested bit by bit by experience. The principle however even at present enters fully into the practise of the Eastern of France Railway, which derives a more complete benefit from it than is the case in Germany, where it has been long in use. Therein lies a lesson which economical railways especially ought to profit by, if they wish to carry out their intended object; to attain which nothing ought to be neglected.

Level crossings are no doubt often a bad thing; and, except in England, where engineers have from the first accepted them very reluctantly, their use has been often abused on main lines; mislead by an economy which is rather apparent than real, as these crossings require a keeper resident on the spot. Secondary lines however, which may be very often relieved from this obligation, ought to admit them more freely; as they then possess many less inconveniences, especially thanks to the simplifications introduced, as we have just seen, in their working.

Besides in France a real improvement in every point of view has been made, by the measure which lodges the workmen on the line, and which confides the gates to the care of women. The working of those crossings, where the companies are bound to place at certain periods of the year a keeper stationed on the spot, always in fact became onerous, when there was no house adjoining the level crossing.

§ XIV. — Rail-Crossings.

254. If the crossing on the level of a railway by a road even causes some inconveniences, it can easily be understood that the passage across one another of two independent railways would be entirely inadmissible. The intersection however of lines belonging to the same railway is in certain cases indispensable.

1st In passenger stations, the main lines are often intersected by lines running across them, to establish communications necessary for working operations.

2nd Goods stations and engine sheds, alongside of one of the main lines of way, are connected with each other by a line which cuts the former, or which borrows from it a certain length, and run upon in a counter direction.

3rd The combination with a main line service of a very active suburban one, having special lines in the stations, may also lead to the crossing of lines (256).

4th Finally, every branch on a double line of way evidently entails the intersection of the departure line on the branch, and of the return one on the main line.

In the first case the crossings are generally rectangular, in the others they are oblique; and at junctions the crossing is longer in proportion as the radius of the connecting curve of the branch is large.

Oblique crossings may also occur in particular cases, as at Marseilles for example. In France trains keep to the left, excepting however on the Strasburg and Bale Railway; in the Marseilles station from local circumstances it was found necessary to invert this order, both departing and arriving on the right hand line and platform. The two main lines therefore cross one another a short distance outside the station. A similar arrangement exists at Versailles ("rive droite"), where each of the main lines may be made available for either arrival or departure; which is a real advantage whenever there are a great many passengers.

(*) In England, at some of the new terminal stations in London especially, there exist some very interesting examples of oblique crossings; as for instance at the Cannon Street passenger station of the South Eastern Railway. The approach to it is over a plate girder bridge across the River Thames, carrying

(*) Note by the translator.

five lines of way; of which two are for the up line or approaching trains, two more for the down line ones, and one is used as an engine siding. The station itself contains nine lines, eight being used for the trains, while the ninth is reserved for empty carriages; these eight lines communicate, with few exceptions. with each of the two up lines and with each of the two down lines upon the bridge. As, in consequence of the position of the station, requiring all the trains to be reversed, each platform becomes both an arrival and a departure one.

Above all it is necessary to reconcile the circulation on each of the two intersecting lines with that upon the other; which is generally done by interrupting the rails of each of the lines for a sufficient breadth and depth to allow of the free passage of the flanges of the wheels circulating on the other line.

The breadth of this passage is, as at level crossings, about two inches; but its length increases with the obliquity of the crossing, so that special measures are necessary to retain the wheels upon the line they ought to follow. This obliquity moreover assists the means of ensuring to the tires a continuous rolling surface, whilst passing over the gaps placed at the acute angles of the lozenge.

255. *Right-Angled crossings.* — If the lines, intersecting each other nearly at a right angle, were of equal importance, they ought to be treated equally; the rails should be on the same level and notched into one another. Generally however the cross line is run over only by single carriages, whereas trains and locomotives circulate upon the main line. It is of importance therefore to have the latter intact, and to effect upon the former all the modifications which are required for the double circulation. The rails R, R (Pl. XIX, figs. 17 to 19), of the main line are preserved therefore continuous, and those of the secondary line *rr*, are notched, and this not merely on the inside of the main line for the passage of the wheel-flanges; they ought to be so also on the outside though to a lesser depth, for the entire width of the tires *mn* (fig. 19), of the wheels which have to run in this groove.

It is in fact impossible to do away entirely with any notches in the rails of the main line, unless the secondary one by a gradual elevation be placed at a level xy, exceeding by at least the projection of the flanges that of the former. The wheels running on this last ought therefore to find, in the more elevated rails of the secondary line, a gap at least equal to their total breadth.

At the outside of the main line the bottom of this gap might be made merely

level with the rail, if the rolling stock was all new; it is however convenient to place it a little lower, in order that the wheels, even when worn near the flange, may bear upon the rail R.

If the elevation given to the secondary line was exactly equal to the projection of the flanges, the wheels while passing over the gap would rest by their flanges on the continuous rail of the main line; any concussions would therefore be suppressed, or at least diminished. But the flanges have not an uniform depth; their projection depends besides both on their own wear and on that of the tire itself. If this projection is greater than the elevation a concussion will take place, and upon the rail of the main line. It seems therefore preferable not to cause the wheels to rest upon their flanges (fig. 19), but to increase slightly the elevation so as to be sure that it will be sufficient in all cases.

If the main line is run over at a certain speed, it is well, to avoid any shock between the wheels and the vertical faces of the gaps, to protect the latter by guard rails placed so as to project slightly beyond the faces (fig. 19).

256. *Oblique crossings.*—The solutions of continuity and the shocks which they entail are at junctions the least of the inconveniences arising therefrom. Experience has but too often shown, that this lozenge, common to both lines run over by the trains, is an essentially dangerous point. Absolute regulations, established in consequence of a series of disastrous collisions, diminish the danger, if the engine drivers will only conform to them; but thereby the trains are brought almost to a stand still, and hence arises loss of time, the more manifest for the fast trains in proportion as the number of branches increases.

Suppression of crossings near to Paris on the Northern of France Railway. — It is possible instead of through crossings to substitute for them crossings at different levels. This effectual though costly, solution has been recently applied on the Northern of France (Pl. XVII), where the crossings on approaching Paris were numerous, in consequence of the very complicated conditions of the service.

Three lines start from Paris: 1st The Paris to Creil, by Chantilly; 2nd the Paris to Soissons; and 3rd that from Paris to Creil by Pontoise.

Five main lines have been established for this object between the Paris passenger station and the goods station; the direction of Chantilly has its special departure line (N° I), for trains to a distance, as well as one for suburban ones (N° IV), and also its return line (N° V), for trains both from a distance and

suburban ones, and which is also common to the Soissons ones. The direction of Pontoise has two lines (N^{os} II and III).

The Chantilly main departure line (N° I), placed on the right of the platform adjoining the side waiting rooms, and hence to the left of the two Pontoise lines (II and III), must cross these to take the direction towards Chantilly. These crossings are shown at A and B of figure 3.

The continuation IV^B of the Soissons departure line intersects at C (fig. 1) the continuation V^A, of the Chantilly return line.

The goods departure line, N° VI, for Chantilly, Pontoise, and Soissons, crosses at D (fig. 1) the line V; it joins at M the continuation of the line N° IV, which branches off at this point, one going towards Soissons by line IV^B, and the other towards Chantilly and Pontoise by line IV^A, which crosses at E and F (fig. 1) the Pontoise lines II and III.

The elevation at the points of crossing A, B, C, D, E and F, has been obtained without exceeding a fall of 1 in 83, or a rise of 1 in 174.

We shall not here enter into a description of the works of art which this solution demanded, and which was complicated by several special circumstances. Not only has any crossing on the level been successfully avoided between the departure and arrival lines, but also any junction between two lines running in the same direction, except at such a distance as to allow the engine drivers on the two parallel lines to regulate their speeds to each other, and so prevent any collision. It is besides needless to add that these arrangements, which are made very clear in Plate XVII, are rendered complete by the addition of ordinary junction signals, worked by the pointsmen.

The whole cost about £ 20,000. With a service so active and so complicated as the Northern of France Railway close to Paris, this certainly is a useful outlay; and it may be mentioned as an example of the sacrifices companies do not hesitate to impose upon themselves, freely and of their own accord, in order to guarantee security to the passengers and regularity in their own service.

(*) In the neighbourhood of London similar arrangements may also be found. As for instance at Battersea, where the West London Extension Railway connects the London and North Western, and the Great Western Railways from the north side of the Thames with the London and South Western, the London Brighton and South Coast, and the London Chatham and Dover lines, on the south side. This it effects partly at the western end, at Clapham

(*) Note by the translator.

junction, where the South Western and the Brighton lines are alongside of one another; and partly at the eastern extremity, where having collected the other branches from the north side of London, it passes them on to the Victoria, Waterloo, and other terminal stations of the southern side of the Thames.

Of the trains from the north, viâ Kensington, and wishing to go westward, the Brighton ones pass respectively along the line V (Pl. XVII[A]), under the Ludgate Branch, O, of the Chatham and Dover, the South Western, A (main and Windsor lines), and the Brighton, R, alongside of which they gradually come up to the level, and form the southern side of the Clapham Junction Station; while the South Western trains, coming from the same direction by the line B, after forming a junction with the aforesaid Ludgate Branch O, of the Chatham and Dover, run with it into the extreme opposite side of the station.

Those South Western trains, still coming from the north, but intended for Waterloo, and passing eastwards along the line C, merely form a junction on the level with the Windsor line of the South Western A, on the north side of it, and run straight into the Waterloo Station; whence they can proceed direct to either Charing cross, Cannon street, or London Bridge Stations. The course of those trains of the London and North Western and of the Great Western from the North to Victoria is rather more complicated; coming along the line H, they pass successively under the South Western A, the Brighton (main), R, and the Brighton (high level), S, then forming a junction with the Brighton (low level), T, they continue in turn under the two high level branches, S, S′, of this last named railway (the second being the one from South London to Victoria), under the high level of the Chatham and Dover M, and having formed a junction with the low level line N, of this railway, they proceed under the South Western A, and across the Victoria Bridge into the Victoria Station.

The Brighton high level branches (the one, S, bringing trains from Clapham Junction, and the other, S′, from South London), pass separately over and above the low level line T, of their own railway, the Ludgate Branch O, of the Chatham and Dover, and the South Western A; they merge into one another a short distance beyond this last point, and before reaching the Victoria Bridge, which they cross.

Of the Chatham and Dover lines (at the extreme south east, and coming from South London, Ludgate, etc.), the high level M, passing above the Brighton low level T, and the South Western A, goes on to Victoria; of the two low level branches, one, N, we have already seen, finds its way to Victoria in conjunction with the Brighton low level T; the other, O, already described as the Ludgate Branch, winds its tortuous course under all the lines it meets, till

it mounts up, passing over the Brighton branch V, as already mentioned, into the Clapham Junction Station, and thence on to Richmond, etc.

The importance of this system of railway connections at this point can very readily be understood; as most of the principal lines from the north, north west, west, south, and south east of the Kingdom have here extensions direct from them, while also all the other railways coming to the Metropolis have unbroken railway communication with this point.

Hence the system here becomes a connection (though the same may also be effected at other places) to all parts of England and Scotland, and when the transit across the Straits of Dover shall be rendered effective for railways, to France and the continent generally.

257. *Arrangement of the oblique through-crossing* (Pl. XIX, fig. 2).— As each of the inside rails 1, 2, 3, 4, are cut off parallel to the outside rail, and at a distance from it of from 1 $\frac{3}{4}$ to 2 $\frac{1}{4}$ inches, there exist two acute points at A, A', and two obtuse ones at B, B'.

It may at once be seen that matters cannot rest thus. For although the gaps are no wider than necessary for the free passage of the flanges, yet the wheels would be no longer guided completely, and violent shocks and even running off the rails would become inevitable.

Let us first consider the acute-angled points. Suppose a pair of wheels upon the line MN, travelling towards the point A. Commencing at the point α the line gradually widens; and, as there is nothing to guide the pair of wheels, if from any cause whatever it is urged to the left, it follows the impulse; it may then strike against the point A with its flange, or even, as there is nothing to oppose a greater lateral deviation, it may turn round the point. This wheel is then off the rail, and its fellow, constrained by the axle, falls like it on to the ballast.

It is by acting on the fellow wheel, that these effects may be prevented. A guard-rail C, C, arranged exactly as on a road-crossing on the level (233), by forcing this wheel to press closely against its own rail, prevents the fellow one from taking advantage of the enlargement of the line.

A similar guard-rail D, D, fulfils as regards the point A, the same duty for the wheels travelling on the other line PQ.

This however is not all. The point A cannot end with a fine point; it is cut off, and is about $\frac{1}{2}''$ broad at the end: the same would take place at β and γ for rails 3 and 1, if they were cut off to a fine point, as we have supposed. A wheel passing from the rail to the point, or vice versâ, would therefore have a gap to traverse; and hence, even at slow speeds, would arise a concus-

sion the more destructive from its falling upon more diminished surfaces.

It is necessary therefore, on one side to afford the wheels as much as possible a continuous rolling surface, and on the other to distribute the pressure over surfaces of a sufficient area.

This object has been succeeded in up to a certain point. Instead of being cut off, along the line $\alpha\,\beta$, the rail is merely bent in this direction, and is prolonged to δ: it presents at this point, similarly to guard-rails and for the same reason, a mouth or opening to avoid any shock from the flanges of the wheels coming upon the point from behind.

This addition, running alongside of the point at about 2 inches from it, eases the latter by relieving it from supporting the whole load of the wheel upon the parts near the extremity, and which are consequently too much narrowed off; as the tire bears upon the bent prolongation, $\beta\,\delta$, of the rail.

To effect this it is evidently necessary, 1st that the point ought to taper off gently towards its extremity, so that the tire despite its conicity may bear upon the rail; and 2nd that the tire be sufficiently broad. Assuming $1\frac{1}{4}$ inches as the necessary bearing upon the rail, the minimum for this breadth may be divided thus.

	Inches.
Flange (of a carriage wheel)	$1\frac{1}{4}$
Thickness of the point at its extremity	$\frac{1}{2}$
Gap	2
Bearing upon the rail	$1\frac{1}{4}$
	5 Ins.

In fact the breadth of the tires is generally at present comprised between 5 and $5\frac{1}{4}$ inches. The Dresden meeting named 5 to $5\frac{7}{8}$ inches as its limits (*). Let us remember also, that this breadth is connected with the minimum radius of the curves, in consequence of the increase they entail in the play of the line (199).

The distribution thus sought to be effected, between the point and the bent continuations of the rails, supposes that these elements, as well as the tires, are in a relative condition which unequal wear and damage alter more or less; hence arise pressures, concentrated, sometimes on one point, sometimes on another, and even with very sensible concussions whenever the speed is considerable. The maintenance of crossings is costly, and they cause a very considerable part of the wear of the tires.

The acute-angled point A, the bent rails, $\beta\,\delta$, $\gamma\,\varepsilon$, wing-rails, as they are

(*) "Vereinbarungen," etc., art. 153.

termed and the two guard-rails CC, DD, form, together with the main rails comprised within the same limits, a very important system, called in the language of railways the crossing. A through crossing from one line to another is not so common; but this portion of it, the simple crossing, is on the contrary of very frequent occurrence, as every change of line entails a crossing as a necessary consequence. While treating of changes of way, we shall again revert to the essential parts in the construction of crossings.

258. *Obtuse angles of the through crossing.* — The system of the two obtuse-angled points is especially termed the dead-crossing. Here the inside rails are necessarily cut off diagonally near the point, and no longer merely bent. The point itself, less liable to damage than that of the crossing proper, on account of its obtuse form and its position relatively to the wheels, acts the same part towards the tapered portion of the cut rail, as the wing-rail does with respect to the acute-angle of the crossing. It relieves it, and affords a bearing surface for the outside of the tire. In crossings as originally made, the four rails cut diagonally were often strengthened by the return pieces, *a*, *a*, *a′*, *a′* (fig. 2), a species of guard-rail; thus was presented close to the obtuse angles four points identical, in form, to the two of the crossings proper, but which the tires reached only on one side. The additions *a*, *a*, *a′*, *a′*, of no real utility, have nearly everywhere disappeared.

There still however remains, between the extremities μ, ν, and μ', ν', of the rails diagonally cut off, a double gap, twice the length of that of the crossing proper. Here also measures must be taken, less to protect the obtuse-angled points B, B′, towards which the wheels are not travelling directly, than to prevent the possible consequences which might ensue from a local widening of the line; namely, concussions of the flanges against the tapering rail-ends, and even running off the line.

A pair of wheels, travelling on the line MN, in the direction of the arrow finds it widened out, 1st on the right hand, on reaching the point ν; and 2nd on the left, after passing the obtuse point B′. The first named enlargement can lead to no further consequence than the pressure, to a greater or lesser degree, of the flange of the wheel upon the obtuse-angled point B; but the latter, and the deviation to the left which it allows of, might cause the flange of the same wheel to strike against the acute-angled point μ, or the flange of its fellow upon the point μ', and even might entail its turning round these points, which would be in fact running off the rails.

These effects are prevented by means of the guard-rail K, which, as it obliges the wheel to press closely against the rail, protects the points μ, μ'. This

guard-rail cannot evidently be continued right up to these points; it must stop opposite the obtuse point B, to leave the passage free on the line PQ.

If both lines be taken into consideration, and likewise to allow that each may be travelled upon in both directions, it will be seen necessary for the same reason to add the three other guard-rails S, L, and R; these four, joined at their ends, form two long guard rails KS, RL, bent in the middle.

At junctions, as the crossings are run over by the trains only in one direction, one double guard-rail would be strictly sufficient; the economy arising therefrom would however be insignificant, and it might be found necessary to run the trains in the contrary direction, as for instance while temporarily working with a single line. Moreover, apart from their direct use, the guard-rails assist very effectively in connecting the parts of the crossing together, which, being as a whole exposed to concussions, ought therefore to be very solidly constructed.

The solution is evidently less satisfactory for the obtuse than for the acute angles of the crossing. The bent guard rail guides the wheel, but not so effectively as the guard rail of the crossing proper; it imparts the direction, but it is cut off too soon to maintain it with certainty.

Concussions are also very difficult to avoid, particularly if the passage be very oblique and consequently the gaps very long, should any alteration in the fixed pieces or the tires prevent the obtuse points from fulfilling their duty properly.

It is for these reasons, that in practise the guard-rails are sometimes placed at a higher level than are the rails themselves. These guard-rails, acting thus upon a larger segment of the wheel, guide it better; nor do they cease to do so when it rebounds under the influence of a shock. On the Austrian State Railway, for instance, the guard-rails consists of a ⊤ iron, KL, bolted flatwise on to a timber longitudinal, and rising 2 $\frac{3}{8}$ inches above the level of the rail (Pl. XIX, figs. 14 to 16). On the Northern of France the guard-rails are formed of pieces of wood B, B, bolted to the wooden frame of the crossing, and protected by flat strips of iron (figs. 3 to 9).

The bent guard-rails experience from the wheels very considerable pressure, tending to straighten them and to force them towards the inside of the line; they are often connected with the outside rail by tie-bolts and nuts, *t*, *t*, *t* (fig. 15). On the Paris and Mediterranean line their fastenings are very effectually eased by connecting the summit of the two bent rails by a tie formed of a piece of rail. On the Northern of France the guard-rails are backed up by five wooden crossties, E, E, E. E, E; three in the central part and two towards the ends of the guard-rails (figs. 5, 7, 8, and 9).

The bottom of the gaps is sometimes protected, both in the crossing proper as well as in the dead-crossing by a flat strip of iron or steel, intended to receive the flange the moment the tire passes off the rail. The utility of this expedient, which supposes the projection of the flanges to be uniform, is disputed. It is objected to, and not without reason, as straining the axles, and tending to cause slipping of the tires, especially of locomotives with six or eight wheels coupled; as in this case the equality of the diameter of the wheels, compelled to assume a common angular velocity, is seriously disturbed by the rotation of one of their number upon its flange. Moreover the vehicle tends, in consequence of this inequality, to place itself obliquely upon the line and to run off it. In the inquiry in 1865 upon the subject, the majority of German Railways, that answered the question, did so in the negative (*).

259. *Past trials of moveable crossings.* — With the inconvenience of the gaps still existing, it was only natural to endeavour to do away with them by the use of moveable pieces. This was tried on several occasions both with acute-angled points of the crossing proper, and with the two obtuse ones, where it was even more desirable, as has been already shown, to do away with these gaps. The points being besides very close to one another are easily connected together by rods, and worked as a single piece by one man.

The principle consists in replacing the four inside rails, for a certain length, by portions moveable upon their supports, and which are thus able to be pressed against the corresponding face of the point, so as to render the rolling surface continuous; the play being at least 2 inches to allow of the free passage of the flanges.

An arrangement tried on the old line from Vesinet to Pecq, on the Paris and Saint-Germain Railway, is shown in figure 1, Plate XIX : the lines in full show the way MN open, as the dotted ones do the one PQ.

The four rails were connected in twos by the rods *t*, *t'*, fixed by crank joints, at 180 degrees from one another, to the bar K, which carried a lever handle, and a counterweight so as to keep the parts pressed against either one end or the other.

If the frame was in the wrong position, a train could, strictly speaking, clear a passage for itself. If, for example, it were to come upon the line PQ when the passage was clear for the one MN, the first wheel on the right, A, would enter between the moveable switch and the fixed rail, and its fellow one between the switch and the guard-rail C; these two switches would then

(*) "Referate über die Beantwortungen," etc., page 59 and following.

assume their reverse position, under the action of the counterweight, which the rod *t* had caused to pass from one side of the vertical to the other. The two other switches, being met, would be altered by the action of the bar, and thus the wheels would find themselves in a proper position.

This self-action of the trains was not however in practise sufficiently certain to be depended upon; a slight obstacle, such as a small stone, would be sufficient to prevent it; besides the working was always done by a pointsman.

A solution requiring a special man, and which besides was liable to eror, could not be accepted : fixed crossings have therefore universally prevailed. More care in their construction and maintenance, both in the elements of the line and in the tires, diminishes the inconveniences arising from these crossings. Besides the more important of them, those at junctions, are run over at a very reduced speed.

Moreover very oblique crossings are avoided as much as possible, in order to reduce the number of types. On some railways only one type is adopted, which is made to fit the different connecting curves; the geometrical preciseness of the laying out is sacrificed thereby (262), but without any real inconvenience in practise.

§ XV. — Points and crossings.

260. *Theoretical setting out. Single crossing for two lines.* — When a line branches off into two, or into a greater number, if the radii are given all the other elements follow therefrom; provided the general principle in setting out be adhered to, of connecting circular arcs by straights which are tangent to them.

The connection of two lines, parallel or nearly so, by means of a third one includes therefore a curve and a reverse one, which ought to be separated by a common tangent. This short piece of straight ought to be at least as long as the greatest length of the frame of the locomotives, so that the two axles may not find themselves at the same time upon two reverse curves.

The elements to be considered in a simple change of way (one line branching into two only) are :

1st The total length of the change of way;

2nd The angle of the crossing point;

3rd The length of the moveable part, the displacement of which allows the trains to be directed from the portion common to both upon one of the two branches, or from each of them upon the common part;

4th The curve of deviation.

1st *Length of the change of way.* — The two lines have one portion in common APB (Pl. XX. figs. 1 and 5), limited by the intersection of the two lines of rails placed on the inside of the system; an intersection which entails the crossing, the general arrangement of which is described above (258).

The length d of the change is the distance from the commencement to the crossing. We have therefore:

A. For a deviation to the right or to the left (figs. 5 and 6), that is where one of the lines is the continuation of the common portion, ρ being the radius of the other line, and e the gauge;

$$d = \sqrt{(2\rho - e)e} = \sqrt{2\rho e} \text{ nearly.}$$

B. For a symmetrical deviation to the right and to the left (figs. 1 and 2), with the same radius ρ,

$$d' = \sqrt{\left(2\rho - \frac{e}{2}\right)\frac{e}{2}} = \sqrt{\rho e} \text{ nearly.}$$

2nd *The angle of the crossing* α.

A For a simple deviation or to one side only; $\tan \alpha = \sqrt{\frac{2e}{\rho}}$.

B For a symmetrical deviation; $\tan \frac{\alpha'}{2} = \frac{d'}{\rho} = \sqrt{\frac{e}{\rho}}$.

$$\text{Whence } \tan \alpha' = \frac{2\sqrt{\frac{e}{\rho}}}{1 - \sqrt{\frac{e^2}{\rho^2}}}, \quad \text{or} \quad 2\sqrt{\frac{e}{\rho}} \text{ nearly.}$$

3rd *Length of the portion modified.* — If the rolling surface for the tires was fixed, it would be necessary first of all, as at the angles of the crossing, to arrange the gaps necessary for the passage of the flanges; the duty of the moveable parts would then be confined to directing the wheels upon one line or the other. The two inside rails would each then be cut along a vertical plane parallel to the outside rail nearest to it, and always at a distance of from $1\frac{3}{4}$ to 2 inches.

Such is the case with the change of way by means of moveable guard-rails, shown in Plate XX, fig. 18; the guiding pieces CN, C'N', acting in fact like guard-rails upon the vertical inside faces of the wheels, assume two positions corresponding to the two directions. But the existence of very long solutions of continuity was a capital inconvenience. The wheel ought to bear as in

crossings, and which thanks to the excess of width of the tire it does, upon the outside rail before it leaves the tapered end of the inside one; but, as soon as the various elements have undergone the slightest alteration, concussions become unavoidable. The theoretical length of the gap, greater in proportion as the radius is large, would be excessive even for a tolerably sharp curve; for a curve of 15 chains radius, for instance, it would be $\sqrt{2 \times 15^{\text{chains}} \times 1\frac{3}{4}^{\text{ins}}} =$ 17 feet. This must necessarily be reduced, and for this purpose the crossing must be placed upon the curve, instead of connecting upon the tangent. With a deviation of $\frac{1}{40}$ the gap would be reduced to $1\frac{3}{4}'' \times 40 = 5'\ 10''$, a passable length; but, however great the radius, the deviation and the gap would not allow the crossing to be traversed except at a very reduced speed.

If this system was in use for a tolerably long time, it is because the objectionable position of the moveable pieces did not cause the carriages travelling towards the common portion to run off. If a pair of wheels AB (fig. 18), running on the oblique line, finds the guards-rails opening the straight line, the groove is filled up by the flange of the wheel A; but the bent extremity MN of the guard-rail forms an inclined plane upon which the wheel mounts, bearing upon its flange. On reaching M, where the guard-rail, having become horizontal, is at the level of the rail, the wheel A is no longer guided, though its fellow is still so by the guard-rail N'C', so long as this is not too far from the rail. At O the wheel A, no longer being either guided or supported, tends to fall into the gap, which it does in fact, provided the speed be not too great. Then things are restored to their proper position.

The speed V ought to be such that the flange should have time, before it reaches the point O, to enter into the groove a sufficient quantity h, without which it must run off the rail. The condition evidently is $V = l\sqrt{\frac{g}{2h}}$ at most. It is not necessary that the height of fall h be equal to the total depth of the flange; it suffices that the rail be retained laterally, excepting that it bears a little more upon the rail. We need not dwell any longer upon this apparatus, which has been completely abandoned and therefore presents no further interest.

Now a days, the rolling surface is made continuous. The moveable portions both support, and at the same time guide the wheels. Hence the condition which determines their minimum length becomes evident. The two lines of the inside rails cannot become fixed except when the distance, separating each from the outside rail next to it, is sufficient for the free passage of the flanges; that is from $1\frac{3}{4}$ to 2 inches.

With rails $2\frac{1}{2}$ inches in breadth, the length l is therefore,

A. For a simple deviation, or to one side only.

$$l=\sqrt{2\rho\,(2\tfrac{1}{2}''+2'')}=\sqrt{9''\,\rho};$$

B. For a symmetrical deviation,

$$l=\sqrt{2\rho\,\frac{2\tfrac{1}{2}''+2''}{2}}=\sqrt{4\tfrac{1}{2}''\,\rho}.$$

This length is that of the chord of the arc; in practice however it is evident that the chord and the arc are very nearly the same.

The double deviation is not always symmetrical.

If the portion common to both branches connects with them by arcs of different radii ρ, ρ_1 (fig. 16), we have:

1st $$d=\mathrm{MN}=\sqrt{2\rho\times\mathrm{AN}}=\sqrt{2\rho_1(e-\mathrm{AN})};$$

$$\text{whence } \mathrm{AN}=\frac{\rho_1 e}{\rho+\rho_1}, \quad \text{and } d=\sqrt{\frac{2\rho\rho_1}{\rho+\rho_1}\,e}.$$

2nd $$a=\omega+\omega'; \quad \text{but} \quad \tan\omega=\frac{d}{\rho_1}, \quad \text{and} \quad \tan\omega'=\frac{d}{\rho},$$

whence $$\tan a=\frac{d(\rho+\rho_1)}{\rho\rho_1-d^2}=\frac{\rho+\rho_1}{\rho+\rho_1-2e}\sqrt{\frac{2(\rho+\rho_1)e}{\rho\rho_1}}.$$

3rd $$l=\sqrt{2\rho\times\mathrm{AP}}=\sqrt{2\rho_1\times\mathrm{BQ}} \quad \text{(fig. 17)},$$

$$\text{but } \mathrm{AP}=\mathrm{AQ}+\mathrm{QP}=\mathrm{AB}-\mathrm{PQ}+\mathrm{QP}=2\tfrac{1}{2}''-\mathrm{BQ}+2'';$$

$$\text{whence } \mathrm{BQ}=4\tfrac{1}{2}''\,\frac{\rho}{\rho+\rho_1}, \quad \text{and } l=\sqrt{9''\,\frac{\rho\rho_1}{\rho+\rho_1}}.$$

4th. ***The deviation.*** — The chord being substituted for the arc over the slight length of the moveable portion, the deviation per unit of length becomes constant over this distance; and we have:

A. For a simple deviation,

$$\tan\beta=\frac{4\tfrac{1}{2}''}{l}=\frac{4\tfrac{1}{2}''}{\sqrt{9''\,\rho}}.$$

B. For a symmetrical deviation,

$$\tan\beta'=\frac{2\tfrac{1}{2}''+\frac{2''}{2}}{l}=\frac{3\tfrac{1}{2}''}{\sqrt{4\tfrac{1}{2}''\,\rho}}.$$

261. *Three-throw switch and crossings* (fig. 3). — If one line branches symmetrically into three no fresh elements are thereby introduced. The distances AM, B′M′, the points M, M′, and the length of the moveable part, are those of the simple deviation; the distance CM″ and the point M″ are those of the symmetrical one.

262. *Modifications in the theoretical setting out,* — The expression $l = \sqrt{9'' \rho}$ gives, in the case of a deviation on one side only, for the length of the moveable portion.

With $\rho = 25$ chains, $l = 35'.2''$.
» $\rho = 20$ » , $l = 31'.5''$.
» $\rho = 15$ » , $l = 27'.3''$.

These lengths are considerable; they would render the moveable portion costly, and difficult of working and of maintenance.

The length is usually reduced to 16′.6″, by renouncing consequently a strict connection upon the tangent; the deviation at the entrance of the curve is then independent of the radius, and equal to 1 in 45.5, which is in no way excessive.

Care must besides be taken to avoid the coincidence of the loose end of the switch with a joint if the rail against which it should press.

It is not however only to reduce the length of the switches and to render it uniform, that a greater or lesser divergence from making the arc tangent to the common portion is allowed. The application, with each radius, of the corresponding value of the angle of the crossing would require a great number of types of points; and with large radii these points would be very acute, the gaps very long, and damage would soon thence arise. For a long time on many lines, especially in Germany, they were careful to preserve the ratio indicated between the radii and the points. In Hanover for example, there were no less than twenty one types, the tangents of which varying between $\frac{1}{6}$ and $\frac{1}{19}$, corresponded to as many radii, comprised between $4\frac{1}{4}$ and 22 chains.

At present the number of types is however there reduced to four; $\frac{1}{12}$, $\frac{1}{10}$, $\frac{1}{9}$ and $\frac{1}{8}$, for deviations on one side only, with one uniform length, 16′.6″, for the moveable portion.

On the Central of Switzerland there are seven types in use; three for deviations on one side only and for the outside points of symmetrical three-throw crossings, and three for the inside points of the last named and for single crossings with deviation to the right and to the left: the seventh type is used merely for lines converging towards turntables.

In France the number is reduced still further; on the Northern, Eastern, and Western, they use only two: 5° 30′ and 7° 30′.

If the combination of one and the same point and also of the same length of the moveable part with several different radii affects somewhat the simplicity in setting out changes of way, it presents no inconvenience, within the limits to which it is applied, to the travelling of carriages; the construction and the maintenance are moreover relieved by it from a very tedious complication.

A further modification is introduced in setting out geometrically the curves of crossings, which consists in placing the point upon a piece of straight several yards in length, so that the carriages when passing over it may have no tendency to lateral deviation. The duty of the guard-rails (258) is thus reduced merely to that of a safety apparatus. The cant of the outer rail is moreover done away with in connections with reverse curves.

To lay out these changes of way, which are very simple on the open line, often on the contrary becomes a very complicated problem in certain stations, on account of the limited space to be appropriated, and of its unfavourable form, as well as by being required to pass through certain points. The data of the question vary therefore with the case, and it is oftentimes only by a close study thereof, guided by considerable experience, that a solution which is relatively satisfactory can be arrived at. One or more elements of a good connection must then be sacrificed; some must yield more or less to the gain of others, the position of the switches must be somewhat strained to be upon a deviation, the curves made sharper, the tangents reduced or even completely suppressed at the points, etc. It is not however within the scope of this work to do more than merely mention here these special cases.

263. *Arrangement of the moveable portion.* — The oldest method of effecting this change was by means of moveable rails; which is in fact the solution that naturally presents itself. The moveable system is formed of two rails, jointed at the end next the common part, and connected by rods; they may be carried across the extension of any one of the branch lines, whatever their number, and fixed in that position.

A train, travelling on one of these lines towards the common portion, and not finding the moveable rails placed in continuation of the line it is on, necessarily runs off the rails. On account of this objection the system has been generally abandoned in favour of that with a fixed rolling surface (260). It may be seen that the objection is not applicable to the junction of the departure line of the branches of Railways having a double line of rails. For, as the trains travel always from the common portion, continuity is here

assured, whatever the position of the moveable rails; which in this case present some advantages over the system at present prevailing, as the switches are met by the trains.

Mr Clapeyron had used moveable rails with the old crossing of the Paris and Versailles line (" Rive Droite"), which branched off at Asnières, by a curve of 27 chains radius, from the Paris and Saint-Germains Railway. The moveable rails were 29′·6″ long, or very nearly the theoretical length; so that the connection was almost exactly upon the tangent. In consequence of their great length and of the absence of intermediate lateral points of support, the rails were obliged to be very solidly constructed in order to resist the horizontal thrust of the wheels; each of them being composed of a bar riveted on to a broad flat iron plate, carrying besides on the inside another similar bar, arranged as a guard-rail; the whole thus possessed considerable horizontal rigidity.

Any how, the advantage of uniformity has here prevailed, and switch-points are now applied to the departure line at junctions, as every where else. The inconveniences arising from the points being met by the trains are moreover greatly diminished by the precaution, imposed on them as a measure of public safety, to slacken on approaching junctions.

264. *Switch-points and crossing for two lines.* — As the rolling surface is continuous the two inside rails of the system are rendered moveable, in this case however it is round an axis placed at the end of each farthest from the common portion; so that each may be, either pressed against the outside rail next to it, so as to afford to the tires a continuous rolling surface, or else drawn back from the rail so as to leave a free passage for the flanges. Each of the moveable rails, being then cut off obliquely in a vertical plane parallel to the fixed rail next to it, presents a tapered form. Hence the term the tongue of the switch.

When the junction is symmetrical, the two switches are necessarily of the same length. This is not however so, if, as is very frequently the case, the deviation is on one side only. This deviation is imparted to the trains by only one of the switches, the other merely preserves the continuity on the straight line, and may therefore be shorter without any inconvenience arising from it as regards the inertia of the carriages. For some time it was thought advisable to take advantage of this property to shorten this switch; the real motives however for doing so are very frequently misunderstood.

When the oblique line is open to a train coming from the common portion, the switch belonging to it is met by it; and, as the wheels have a tendency to

continue on the straight line, their flanges acquire by this very fact an inclination to strike against the end of the switch-tongue, however little it may project beyond the inside face of its main-rail. If any concussions take place the end of the tongue becomes altered in form, and the harm done progresses rapidly. It may even happen, that, if the switch of the deviation line is not pressed up against the rail, a flange, thinned by wear and keeping close to the rail, might insert itself between it and the end of the tongue; when it would continue on the straight line, while its fellow wheel would be on the oblique one : of course the carriage would then run off the rails.

At present as will be seen further on, the switch-tongue of the deviation line is conveniently protected by the rail itself. Formerly this was not so; in order to avoid the effects just mentioned it was sought to keep it away from the flanges, and this by the same method as pointed out (257) for crossings, viz., by acting on its fellow wheel by means of a guard-rail which obliged its flange to keep close to its own rail; at the same time it is true this flange was also brought near to the end of the switch-tongue of the straight line, when open. No inconvenience however arose from it, as this switch, having no deviation to impart, was not exposed as was the other to the pressure of the flanges, and its tongue, in consequence of its lesser length, was protected by its position within the obtuse angle formed by the switch and by the portion of the rail belonging at the same time to the straight line and to the oblique one.

To be effective the guard-rail ought necessarily to be placed, opposite the point to be protected, at a distance of about 2 inches from the rail beside which it lies. If therefore the switch of the straight line was as long as that of the oblique one, its play at the end, even supposing it to have no thickness there, would be limited to 2 inches; and this would be the same for the switch of the deviation line, connected with the former.

But the amount of play ought to be much greater than this (266). By reducing the length of the switch of the straight line these different circumstances have been placed in harmony. As thereby the switch of the deviation line was enabled to have its necessary play, while the other found between the rail and the guard-rail the space it required, not merely through its reduction in length, but also by the increasing interval between the two rails.

" Formerly" says Mr Brame, an engineer of the ' Ponts et Chaussées ' (*), " in " points and crossings a guard-rail was required, the object of which was to bring

(*) " Report upon the experiments made by the Northern of France Railway for the improvement of the line " (" Annales des Ponts et Chaussées, ") vol. XX, 1860.

" the wheels of the carriages as near as possible to the axis of the main rail next the " short switch, the point at which the width of the line is greatest; and consequently " to ensure the bearing of the wheel tires at that side. "

The object of the check-rail could not evidently have been the one ascribed to it by Mr Brame. In order to avoid any danger of running off while crossing the widened parts the wheels ought, far from being forced into one of their extreme positions, to be maintained in their mean one.

The diminution in the length of the switch of the straight line had for its object therefore the protection of the tongue of the switch of the oblique line.

The result of this inequality in the switch of the straight line is, that, when this line is open, it lies within the obtuse angle AOB (Pl. XX, fig. 19), and thus is itself protected against the action of the flanges of the wheels. It however is but a slight advantage, this switch not being exposed as is the other to the concussions of the rails.

On the other hand there is no reason now a days for this guard-rail, which was of undoubted utility so long as the switch-tongue of the deviation line had not been successfully protected in a direct manner; the unequal length of the switches which is a necessary though unfortunate consequence of the existence of the guard-rail ought therefore to disappear with the latter.

The inconveniences arising from this inequality, which has still some few partisans, are serious. As for instance; it requires two different types, one for a right hand deviation, the other for the left hand one. This is one complication, but it is not all. It sometimes happens at a station, in a moment of hurry, the proper type not being to hand, the other is used. It is then the short switch that imparts the deviation, which becomes consequently very sudden; and hence, though the speed be slow, ensue runnings off the rails. Several have been seen by the author, which were due to this cause.

In addition the straight line widens out from the commencement up to the point of the smaller switch-tongue; where the excess of width is 1 ½ inches with the ordinary lengths, 16′ 6″ for the long and 12′ 0″ for the short switch. Hence arises a new and very serious cause of running off for wheels with narrow tires and worn flanges; as one of the wheels no longer bears upon its rail, while the fellow rests upon its one. Sometimes this danger is partly diminished by reducing the gauge of the lines between the switches and the crossing; however it is evident that this reduction can be but very slight, as the reasons which lead to the adoption of play in the gauge (199) exist at changes of way as elsewhere, and more so even; as one of the branch lines, if not both of them, often deviates by a curve of slight radius, 15 to 12½ chains, and sometimes less, and where it is important to assist the inscription of the flanges of the

wheels. This narrowing in at the beginning cannot therefore exceed about $\frac{1}{4}$ inch; which still leaves at the end of the shorter switch-tongue an excess in width of 1 inch.

The guard-rail moreover creates a special obstacle for certain locomotives with a very long frame, such as are made at present, while passing from the common portion to the deviation. Their change of direction is effected at first (265) by pivoting upon their middle pair of wheels, and during this movement the hind wheel next the guard-rail presses against it; the whole system is then in an abnormal condition, which may in certain cases lead to its leaving the rails. We may add, it is true, that this danger is considerably diminished by the longitudinal play, which, to facilitate circulation in curves, is now often given to the end axles of locomotives.

The inconveniences of inequality in the length of the switches would, according to some engineers, be counterbalanced by an advantage special to it.

" The two switches " says the late Mr Perdonnet (*), " are made of unequal lengths " in order to prevent the wheels of the same carriage entering at the same time upon " two different lines. In fact, supposing that, in consequence of a small stone or " any other obstacle upon the line, the switch of the oblique line is prevented from " closing up completely, or else that the two switches are in an intermediate position between their two proper ones, owing to the switch-bar apparatus being rusted " and not working correctly; the flange of one of the wheels of the locomotive at " the head of the train, getting behind the switch of the oblique line, upon the " straight one, would push this switch aside, and the short switch following the " longer one, would then press against the fixed rail.... If, on the contrary, the " switches were of the same length, and both wheels reached them at the same " time, one wheel would follow the straight line, the other the curved one. "

The object intended in making the switches of different lengths was not, as has just been stated, to prevent the two wheels on the same axle from entering one upon one line, the other upon the other; the intention was simply to render a check rail possible.

If this inequality had in itself any advantages, it doubtless would matter little whether the advantage was made the object, or merely a consequence of the system; and as such it ought to reckon against the inconveniences just mentioned. But, supposing the case stated by Mr Perdonnet, of the switches stopped in an intermediate position by some accidental obstacle, the effect he points out, of one wheel following the straight line whilst the other got upon the oblique one, would take place just as well with equal as with unequal lengths of switches. As soon as the space between the deviation switch-tongue,

(*) " Traité élémentaire des chemins de fer, " 3rd edition, vol. II, page 149.

badly closed, and the rail, is supposed to be wide enough to allow of a flange entering it, it is no way necessary, in order that the flange should continue its course, for it to push back the switches by raising the counterweight; especially is it impossible for it to force them hard back on the other side, so as to press the switch of the straight line against its own rail. This effect takes place with self acting switches when taken from behind; this does not arise owing to the flange which finds its passage stopped having made a way for itself between the switch and the rail, but because the two wheels, the outsides of their flanges being apart a distance equal to the gauge of the line less the allowance for play, can only make room for themselves by pressing the switch opposed to them hard up against its rail.

The distance between the outside faces of the switches measured at the tongue is usually 4'.4", whilst the width between the insides of the flanges is 4'.5½"; it is possible therefore for both switches to get between the wheels, since the width between the former is less than that between the latter. This accident however is possible with switches of unequal length just as well as with those which are equal. An intermediate position of the switches would moreover often entail as a consequence a concussion between one of the wheel-flanges and the switch-tongue on the same side; this may take place upon either side, and, like when both switches get between the two wheels, it is possible just as much with switches of different lengths, as with those which are equal. In both cases a careful supervision and maintenance, as their well as being kept constantly well greased, are indispensable.

Besides, facing points are generally either padlocked, which ought only to be possible at the full extent of their throw, or else they are held down by a poinstman. It is in these measures that the true guarantee lies against running off the rails. Any intermediate position must be absolutely prevented; it does not suffice to oppose the consequences thereof by any such expedient as switches of unequal length, which on this score have no attenuating influence, and besides cause very serious inconveniences.

The opinion of engineers is however at present nearly unanimous on this point. The check-rail has been done away with, since the switch-tongue of the deviation line can be protected without it; and inequality in the lengths of the switches has also generally disappeared with the check-rail, which was its only excuse.

We may add however that an important railway, the Southern of Austria, is an exception, at least partially.

"At first" says Mr Bontoux, Engineer "des ponts et chaussées", the traffic manager of this system, "there existed on the Hungarian lines switches of equal lengths, and

' running off at these points was of frequent occurence; now however they have all ' been changed, and the result is very satisfactory " (*).

It is difficult to understand how this inequality, which actually is very slight, could have much influence in this result; due without doubt to an improvement in construction, in laying down, and in after maintenance.

On this line also is to be remarked a peculiarity, which as far as the writer knows exists but there. It is that these crossings with switches of unequal length have often the shorter one on the longer arc, that of the deviation line; this occurs, for example, at Grätz and in its neighhourhood.

According to the explanations given to the author, this apparent anomaly is on the contrary a rule, though imperfectly carried out it is true. The object of this arrangement would be to cause a smaller amount of cutting away, and consequently to weaken in a lesser degree the switch which is submitted to the pressure of the flanges.

But on the other hand the deviation is more sudden; however, no unpleasant effect, it is said, arises therefrom "as the angle of deviation is not much augmented." Which amounts to saying, that the use of the short switch on the deviation line has no inconvenience, because it is nearly as long as the other. Why then not make them equal? or, if the inequality be accepted with the consequence it entails of two different types, why not take advantage of it at least to soften down the deviation, by the small benefit arising from this slight inequality?

265. *Running off at facing points, though properly placed.* — It is of frequent occurrence, that a running off takes place at facing points, though they are properly set and in good order. The cause thereof is often complicated, and sometimes difficult of discovery. The deflexion of the deviation switch contributes to these accidents. This switch, over 16 feet in length, is stiffened laterally by two stops *h*, *h* (Pl. XXI, figs 1 and 9), generally about 3 feet apart. When it is firmly pressed by a wheel-flange in the middle of the interval between the two supports it bends; and each time it yields an amount f there is a corresponding deflexion at the point, but in a contrary direction. If the wheel acts between the heel and the first stop this is about equal to $\frac{f\,13'}{1{\cdot}66'}$, and if between the two stops to about $\frac{f\,9{\cdot}83'}{1{\cdot}66'}$; to cause a displacement of $\frac{3}{4}''$ at the point, the deflexion f would in the first case have to be $\frac{3}{32}''$, and $\frac{1}{8}''$ in the second one.

(*) Letter dated April 21st 1866.

A lesser deflexion may however be sufficient actually to produce it, in consequence of the state of vibration the whole system is in, and of the whipping movement of the switch. It is true, that when this last is acted upon by a flange towards the heel there is generally in consequence of its length another wheel-flange keeping the point in its place; thus explaining how runnings off are not of more frequent occurrence. The extremity of the tongue is however free when the hind wheel of a locomotive, running by itself, reaches the heel; this may, as can be readily understood, cause a running off, especially if the locomotive, having a long and very stiff frame, and travelling too fast, acts with much pressure upon the heel of the switch. On this account, among other reasons, should switches have horizontally very considerable rigidity; on this score therefore, as well as on that of stability, those which have the inverted ⊤ rail form are much to be preferred to the double headed ones.

The passage of very long framed locomotives has a tendency to produce also an analogous result, but which is due to another cause. The front wheel constantly urges with its flange the deviation switch outwards. If however it has nearly reached the heel, or worse still gets beyond it, before the hind wheel arrives at the point, the switch may be urged towards the inside of the line by the middle wheel. In fact, as soon as the hind wheel in its turn presses with its flange against the rail, the engine pivots upon its point of application in order to change its direction; the middle wheel must then either slip transversely upon the switch, or carry this with it in its movement, and, as the friction of the tyre upon the switch is much greater than that of the latter upon the greased plates, the counterweight may be raised and the switch sufficiently opened to allow of the flange of the hind wheel getting behind it.

266. *Throw of the switches.* — Each switch in one of its extreme positions is pressed against the rail with the tapered portion of its outside face; in the other it ought to leave a free passage throughout its length between itself and the rail of at least 2″, in fact to place parallel to the rail the portion of that face which is not tapered off. The free space between the rail and the tongue-point, or in other words the distance the latter would have to travel in passing from one extreme position to the other, would therefore be $2'' + 2\frac{3}{8}'' - \frac{5}{8}'' = 3\frac{3}{4}''$; if the extreme point is cut off, as is always the case, so as to allow of a thickness of $\frac{5}{8}''$ at the tongue end.

It is however more prudent to exceed this amount of throw; for, though sufficient to ensure the free passage of a flange coming from the common part,

yet once the latter has got between the switch and the rail the amount might sometimes not suffice to guide it with certainty in this direction.

Suppose a rail A (Pl. XX, fig. 11) with its flange, reduced by wear to $\frac{5}{8}''$, pressed against its rail, the distance between the inside of the flange of the fellow wheel B and its rail would then, with a width of $4' \cdot 8\frac{7}{8}''$ for the line and $4' \cdot 5\frac{1}{2}''$ between the tyres, be $4' \cdot 8\frac{7}{8}'' - (\frac{5}{8}'' + 4' \cdot 5\frac{1}{2}') = 2\frac{3}{4}''$; this would leave, with a working distance of $3\frac{3}{4}''$ between the rail and the switch, a play of $1\frac{1}{8}''$, sufficient to prevent the flange of the wheel B striking against the point α. This amount of play may however be diminished by lateral wear in the rail, by a wheel becoming partly unkeyed, by the deformation of a flange, etc. The above distance would be therefore working it too fine; it is found better consequently to augment slightly the play, and with it the throw common to both switches, which hence are no longer parallel, but converge slightly at their points.

The amount of throw at the extremity is generally made $4\frac{3}{4}''$, and sometimes more; there is however no advantage gained by exceeding this figure, indeed some inconvenience might arise from so doing as regards the danger of running off indicated above (264), as the two points may, the more easily as their distance apart is less, get between the two tyres.

This increase in the throw requires, either that the switches should converge slightly, if their centre line is straight, or else that they should be a little curved. This last has besides the advantage of reducing the part of the web which is tapered off; the curvature is placed where the switch presses against the main rail.

267. *Three-throw switches.*— It is evident, that the moveable rails already spoken of (263) are applicable in this case, as well as in that of single-crossing switches, but with chances of more serious mistakes. Being abandoned in the latter case, with greater reason is this done with three-throw points.

It may be seen at once (Pl. XX, fig. 3, and XXI, fig. 9) that the four inside rails can only become fixed when the distance between the two faces next to each other amounts to 2''. Between this spot and the commencement of the change of way, each rail is replaced, as in the single crossing, by a tapered switch, pivoting upon its heel; these switches are connected together in pairs, the outside one on one side of the centre line with the inside one on the other side. If, for example, the middle line of way is open, it is clear that it is sufficient, in order to open either of the other two lines, to operate with one only of the systems of switches without altering the other.

The four switches cannot in this case be all of the same length, since it is

requisite, that the switch belonging to one of the side lines should, whilst opening its own way, leave room between itself and the fixed main-rail for the switch of the middle way, on the same side.

On each side therefore of the centre line of the railway there is a long and a short switch; but the order in which they are placed may vary; it may be the same on each side, or different.

Three separate dispositions may therefore occur (Pl. XX, figs 12 to 14).

1st The two short switches outside (fig. 12).

2nd The two short switches inside (fig. 13).

3rd The short switch on one side inside, and on the other outside (fig. 14).

In the two first, each as a whole is composed of two systems of a long and a short switch coupled; in fact, of two sets of single points and crossings with unequal switches, but with the order inverted in each.

The third is formed of two sets of single points and crossings with switches of equal length in each set, but having the lengths of the two sets different.

Each of these combinations has its advantages, as well as its inconveniences.

The first form, with the two short switches leading to the middle line, tends to cause for this line a considerable increase in the gauge at the tongue-point. With the long switches 16′ 5″ long, and the short ones 11′ 10″, this excess in width amounts to $2\frac{3}{8}''$; which can be only very slightly reduced even by narrowing in the opening.

In the second, as the smaller switches belong one to the left hand line, and the other to the right hand one, there is no increase of width to the middle line.

With the third form, as this excess of width affects only one side it is reduced to $1\frac{3}{16}''$; retaining the same length of switches as above.

The second arrangement would therefore seem the best, and the first one the worst; nevertheless this is the one most in use. This arises from the fact, that generally three-throw crossings consist of two alterations in direction, one on the right and the other on the left (Pl. XX, fig. 3, and XXI, fig. 9), and of a middle line in continuation of the common portion, which is the one most used. As the short switches are less weakened by being tapered off than are the long ones, there is hence a certain advantage in placing them on the line which is most used; and on the other hand the deviations are then produced by the long switches.

This augmentation in the width may be decreased by diminishing the difference between the length of the switches, but then they must be more tapered off. Thus, on the Orleans railway with double-headed rails this difference is reduced to 15″ in a symmetrical three-throw crossing; the long switches being

16'·0", and the short ones 14'·9" in length. On the Austrian " Staats Bahn " the difference is 2'·0", with the long switches 16·5" and the short ones 14'·5" long.

Any how, three-throw crossings are considered, and properly so, as a defective apparatus. They are only used in cases of absolute necessity, where want of space does not allow of two successive junctions; especially are they to be excluded from main lines. The Eastern of France has within a short time done away with several. At the Dresden meeting of 1865 their exclusion from main lines was also recommended (*).

Sometimes it is desirable to avoid even a connection between two lines only, as for example where a work of art upon a double line temporarily becomes a single line one. Both ways are still retained, but they are laid almost upon one another (Pl. XX, fig. 15); the different elements are then all fixed. This arrangement, designed to avoid any facing points and the consequent slackening in speed, has been used on the railway from Leipzig to Dresden, and on the Cologne and Minden line during the repairs to the bridge over the River Leine.

269. *Working of the points.* — The switches ought as much as possible to be run over by the trains in direction from the heel to the point. This rule, which evidently cannot hold good at the entrance of sidings on single lines, is always observed on double ones, whether for shunting lines or for the connections which at certain distances exist between the two main lines of way.

This arrangement affords several advantages. For if the trains meet the switches of a siding line, and should their points be wrongly set, these trains, instead of following the main line, might be thrown into collision with a shunted train; but with the reverse arrangement this serious danger disappears. Also with this last method trains on the main line clear a passage for themselves, when the switches are badly placed, by the action of the flanges bringing them back again to their normal position. We shall refer shortly to this action under the head of self acting switches.

To require all trains, needing to shunt, to get upon the siding by backing, has no doubt its inconveniences. As the head of the train must first advance upon the main line sufficiently to allow the tail to get past the switches, then stop, open the deviation line, and back upon it. It is more particularly goods trains, that are required to shunt in order to allow passenger trains to

(*) "Vereinbarungen," art. 67.

pass them; this kind of train is heavy and often very long, and to back them is sometimes difficult in consequence of the heavy load and the amount of slipping.

To shunt by backing is therefore much less expeditions than doing so directly; this is an actual inconvenience, the more so that the guard often only determines to shunt when he is pressed for time. But there is with it no danger of collision, provided the regulations respecting signals be carefully observed; in any case the danger is much less than with direct shunting.

On another score it is much better for the switches and for the rolling stock, that the former be run over in direction from the heel to the point; as this last is not then exposed to any concussions from the wheels. The same remark applies to the extremity of the crossing which is, like the switches, taken from behind.

To allow the trains to work switches which they approach in this direction is constantly done in England, and it must be acknowledged that the accidents caused by this kind of working are few. It does not however deserve our absolute confidence. Switches do not always obey, especially the action of light carriages. The switch belonging to the line the train is not upon is acted on by the wheel-flanges, getting like wedges between it and the main rail; but the other one, displaced principally by the first by means of tie bars, has to give place while under the load, and thus tends to bend and to get out of shape. The arrangement is also often forbidden; for example on the Eastern of France railway (*). This property is therefore only recognized as affording a guarantee against the consequences of a badly placed switch, and as becoming the responsible agent thereof in default of any other.

269. Switches ought to have but two positions, each at the end of its throw, and corresponding respectively to the opening of each of the two ways. These two positions are given to them by means of a working lever, with a counter-weight, sometimes fixed, but more generally moveable upon it (Pl. XXI, figs 2 and 10). If fixed, the switches when left to themselves tend always to resume their original position, that is to keep the same line of way clear; to open the other line it is therefore necessary to retain the counter-weight raised. If however this is moveable, the switches open either line at will, according to the position given to the weight relatively to the lever.

The most manifest advantage of this last arrangement is the power of en-

(*) General order N° 9, respecting the working of switches. Art. 13.

trusting several switches to a single pointsman, even when they require to be worked almost simultaneously; this is impossible if the counter-weight is fixed, as they must be retained suspended by hand during the whole time occupied by the trains in getting upon, or leaving the deviation line. Besides, with the weight fixed, if a careless pointsman lets it go prematurely, the train, finding itself on two different lines, is cut in two.

Different arrangements have been devised to render this operation less tedious and more certain. Figures 20 and 21 of Plate XXI show that which has been successfully tried for some time back on the Southern of France Railway : the counter-weight P, merely running on the handle which carries it, slips when this is raised and places itself against the curved lever LM ; a very slight pressure is then sufficient to retain the system in this position, and on being set free it resumes its original one.

A fixed counter-weight has besides but one advantage; that of establishing with certainty, and without any necessity of its being verified, continuity in the same direction. This consideration is not without some weight for railways having double lines of way, for the most part of the time run upon very unequally as regards the two directions served by the switches. It is not however of a nature to be set against the advantages of a moveable counter-weight. Besides it only needs to add to the latter a pin, which may be padlocked, and thus allow the weight to be fastened to the handle of the lever, to obtain at pleasure the advantage attached to a fixed counter-weight.

In fact the use of a fixed counter-weight is confined to those switches which are rarely worked in deviation; for instance, to certain facing switches on main lines. But, as the switches may be padlocked, the surest guarantee against their false position, just as well with a moveable as with a fixed counter-weight, there remains no reason for any longer giving the preference to the latter. It is only requisite, that this padlocking should be effective, and not, as is often the case, done by merely connecting the working lever with its frame by means of a chain, which the pointsmen can leave somewhat loose, to save themselves opening the padlock when the switch has to be worked. The chain then ceases not merely to be a guarantee, but it becomes a source of danger, since it limits the throw. The connection ought to be not with a chain, but by means of a rigid bar, into the fork of which the padlocked pin can only be fixed when the points are at the end of their throw; to operate upon the switch-tongue itself is however even still more certain.

270. As far as regards the self working of the switches by carriages taking them from behind, the two arrangements of the counter-weight may be con-

sidered as equivalent to one another, as long as the counter-weight is not loose upon the lever.

That the self action of these points is but moderately certain is not their only objection. The switches are brought back sharply by the counter-weight as soon as a pair of wheels leaves the tongue, and thus the whole system experiences, when traversed by a train, a series of destructive shocks. This property of self action is however generally only made use of for working single locomotives.

The inconvenience just mentioned would disappear if the counter-weight was so arranged, that the switches should remain fixed in the position imparted to them by the first pair of wheels, which thus would open the line for all those following; and the crossing would be passed over without the whole of the train experiencing a series of concussions. The only duty of the counter-weight would then be to place the switches on either side, at the extremity of their throw, and to retain indifferently one or other line open; a state of things admissible, especially on railways with a single line, where the trains travel just as often on the second line as on the main one.

Mr Bender, an engineer of the Austrian Railway C°, has proposed an arrangement for single line railways, which has been applied in numerous instances in that country.

The rod which works the switches is jointed to a crank, keyed on to an upright shaft, which also carries a cast collar with two helicoid cams above it.

Above this last is placed the counter-weight, a cast cylinder with the shaft passed through it, and having on its underside two projections which fill up exactly the interval between the cams. A stop, fixed on the frame which carries the socket and the upper bracket of the shaft, has free play in a longitudinal groove in the counter-weight, and prevents it turning with the shaft.

The parts are so arranged, that, when the switch-tongue is displaced by a quantity equal to the minimum thickness of the wheel-flanges, the shaft turns through an angle greater than that contained by the half projection of one cam; whence it follows that the counter-weight, after being raised by sliding along one side of the cams, falls down the other, forcing the shaft and with it the switch-tongues to continue their movement till they attain their extreme position.

A washer, or species of collar, fixed on the shaft, limits the play of the weight when the switches are suddenly displaced.

With switches worked by hand this arrangement amounts to the same as when the ordinary counter-weight is moveable upon the lever. It contains

no special property except for trailing points set by the trains, and on this account it might have been favourably accepted in England; it is however often preferable on double lines, that a train having altered a switch, should leave in it its original position. As the mechanism for this purpose is moreover less simple and less certain in action than the ordinary apparatus, it is only natural that the latter should be preferred on continental railways, where the English or self acting system is but little used.

It must howerer be allowed, that Mr Bender's counter-weight would do away with the cause of very numerous accidents which take place in stations during shunting operations. It often happens that a train after backing has to go ahead; if during the former operation it takes from behind a self acting switch opening another line, and, if it stops and resumes its forward movement before the switch-tongues are cleared, the train then finds itself on two lines; hence arises a running off, or a fracture of the couplings, or both. The engine driver from the end of a long train cannot always be exactly aware of his position as regards the points, and any want of attention on the part of the luggage guard or a signal wrongly understood is sufficient to cause this kind of accident.

271. Figures 17 to 19 of Plate XXI show the working mechanism in use on many German railways, and arranged to work with a signal indicating the position of the switches, signals which on these lines are often multiplied to excess.

This arrangement is exempt, as are others also, from an inconvenience which is common to the counter-weight with moveable handle employed in France. It happens sometimes with this last, that, when a pointsman is working quickly several switch-levers in a row, he imparts to the counter-weight so great a movement as to cause it to make a complete revolution round the lever, thus bringing the switches back to their original position.

272. *Working switches from a distance. Locking apparatus.* — In general, whatever the details of the arrangement, the working lever is at a few yards only from the switch. The great multiplication of railways, as well as the enormous and actively circulating traffic upon them, has at all large terminal stations and important junctions necessitated the collection of many signal and point levers together; thereby placing them under the eye and working of one pointsman only, and doing away with the many chances of serious if not fatal mistakes arising from several men passing hurridly from one lever to another. Still further to ensure the safety of the passengers, different mechanical con-

trivances have been applied to maintain a system of obligatory harmony between the various signals and points in the different positions they are called upon to assume; the object being to counteract, if not to render impossible, any error on the part of this single pointsman.

In England, where the railway system has received its most extensive development in proportion to the population, and where the amount of traffic, especially of passengers, is so great in some places as to require an almost incessant circulation of trains, particularly in and near London, occur naturally the most numerous examples of this grouping together of working levers; as for instance, at all the large Metropolitan termini, at populous towns such as Manchester and Liverpool, and at important junctions, as Crewe, Chester, etc.

On the continent also, as at Paris, and on the Northern, the Western, the Southern of France, the Lyons and Mediterranean, etc., and wherever the exigencies of the traffic require it, the harmony system is being gradually introduced. As for instance, at the Moret station of the Lyons and Mediterranean Railway, where the lines to Burgundy and to the Bourbonnais branch off.

The wooden signal box, placed at a considerable elevation in consequence of obstacles impeding the view, contains sixteen levers, five point and eleven signal ones. Its principal peculiarity, as far as regards working signals from a distance, lies in the fact of the simultaneous action by the same lever of the points at both ends of a line connecting the two main lines not far from their point of junction, and on which trains from the Bourbonnais have to run into the station. The nearest of these points is over 70 yards, the farthest about 150, from the signal box; the lever is however rather more difficult to move, than would have been one working a single set of points at even more than 200 yards distance.

The Paris and Mediterranean R^y C^o, while establishing this locking apparatus, had in view more important applications of the system, especially at the station of Perrache at Lyons.

To effect this object, of harmony of actions among the various signals and points, all the working levers are collected in a wooden hut, with the upper part of the front and sides in glass, placed at a sufficient height, either along side of or above the lines at the entrance to the station, and in such a position as to command all trains approaching to or departing from that end of it.

All the levers, whether signal or point, belonging to lines of the same group, that is, which are cut off or connected with each other by switches, are made to lock into one another, moving simultaneously with each other, and ren-

dering it materially impossible that two opposing lines of the same group should both be open at the same time, or that conflicting signals should be displayed regarding them. Nor is it possible to work the points which give access to a line or to place its signal at "all right", until the "danger" signal has been given for all lines communicating with it. And to further assist the memory of the signalman, where the number of levers is great, it is sometimes usual to inscribe on the side of each lever the numbers in order corresponding to each of those levers, which it is necessary to adjust in order to release the desired lever.

Thus when a train, previously announced by telegraph, finds that the signals before it give it permission to proceed, it may be certain that the way before it is clear; and that it is physically impossible for any train upon another communicating line to get upon the rails it proposes itself to travel upon.

This system of collection of levers requires in many instances lengthened communications and ingenious arrangements for transmitting in different directions the movement of the lever to the corresponding point or signal; especially is this the case with distant signals, some of them as far as 200 yards, and even more, from the signal box.

To carry out these various precautions for the safety of railway trains and of their passengers many mechanical arrangements have been devised. The first successful application of the principle of interlocking seems to have been applied by Mr Vignier, of the Western of France Ry, in 1855 to the terminal station of that railway in Paris. Shortly after this Messrs Saxby and Farmer devised their well known system; and many others in England, such as those of Messrs Anderson, Brady, Skinner, etc., were introduced to effect the same object.

A few of the most successful and most extensively applied of these systems we will endeavour to describe, sufficiently to enable the principle of each to be understood; for it must be borne in mind, that the exact application varies in each individual case, and that the mechanical contrivancies alter with the number and position of the points and signals in each group, as well as with the number of groups to be dealt with.

Mr Vignier's system consists in connecting with each lever near to its lower extremity a flat bar placed edgeways, which slides horizontally in front of it, advancing and receding with the motion of the lever; in this bar at certain distances, as required, are punched circular holes to allow of the passage through them of round bars or bolts, which are shot in a direction across the line of action of the levers, and longitudinally with the lever frame; thus

locking the further progress of the sliding bar, and with it that of the lever. These locking bolts are attached by means of a bell-crank to the flat sliding bar of that lever, which desires to retain or lock another in a certain position; the number of bolts branching from and actuated by the crank depends upon the number of levers requiring in each case to be locked or left free, and the length of each bolt varies with the position of the lever it has to lock. Figures 1 and 2 of Plate XXXVII show an application of this method wherein there are 5 levers; in the position there shown lever N° 2 is in its hinder or "all right" position, and locks, or retains in their forward or "danger" one, levers N°ˢ 1, 3, 4 and 5. The transverse sliding bars are marked *a*, and the locking bolts *b*.

In Messʳˢ Saxby and Farmer's apparatus, as generally constructed when on the spindle principle, the locking of the levers is effected by means of broad plates with a projecting notch or shoulder, and placed flatways between each pair of levers, so that by a certain amount of movement to the right or to the left each locking plate may place its broad shoulder before or behind the lever along side of it, according to the direction in which its progress is to be barred. This facility to move sideways is obtained for the locking plates by making their hinder extremity into an eye, pivoting round a pin which supports them; while the front end is forked and rests upon a flat sliding bar, clipping with its fork a pin in the latter to keep it in position.

This flat bar, resting upon standards at such a level as to maintain the locking plates horizontal, runs the whole length of the lever-frame, and is free to slide longitudinally with the motion sideways of the locking plate; and, since to this sliding bar are also attached the locking plates of the different levers which it is desired to place in harmony of action with each other, each bar may be said to represent a distinct position or note in this system. These bars are placed horizontally in tiers, together with their respective locking plates, one above the other; they are generally situated in the locking frame under the floor of the signal hut.

The method of transmitting motion from the levers to the locking plates varies much with the circumstances of the case. It may be effected by the lever itself pressing along a wedge-shaped projection in the side of the locking plate next to it, gradually displacing it and imparting to it a motion sideways, which is also communicated to the longitudinal sliding bar, and through it to all the other locking plates in communication with it. Or again, the lever may be connected near to its lower extremity directly with the longitudinal sliding bar in front of it by means of a bell-crank or other mechanism; thus causing the bar to travel to the right or to the left, and with

it the locking plates attached, while the lever itself moves backwards or forwards.

The locking plates themselves vary in shape according to the duties they are intended to perform. Figure 5 of Plate XXXVII shows several of these forms; *c* is intended to retain by its notched shoulder the lever to its left, N° 1, in its forward or normal position, while should the lever be in its backward position, and that this locking plate should have been by means of the sliding bar drawn in front of the lever, this can, should nothing else lock the sliding bar, resume its forward position by pressing along the inclined face of *c*, and so push this back again to the right; *d* acts in the reverse way to *c*, retaining the lever, N° 1, in its "all right" position; *e* has two shoulders, and locks the levers, N°s 2 and 3, on either side of it, according as it is made to travel to the right or to the left; *f* is merely a means of transmitting motion from its lever, N° 4, to the sliding bar, and so of locking or releasing other levers as required, but itself it is unable to lock any lever; *g* shows the bell-crank by which lever N° 5 acts directly upon the sliding bar.

In order to simplify the arrangement and to assist the signalman in his operations, the following measures are adopted by Messrs Saxby and Farmer. On a brass plate, running along the extremity of the quadrants of the levers, are engraved the numbers corresponding to the points they close or the signals they place at danger; while a similar plate at the back of the levers indicates those that are set right by the pulling back of each lever.

In arranging the various levers on the frame it is usual to group together the down signals, and in another part to place the up ones; the point levers are generally painted black, while red is reserved for the signals, unless they are very numerous, when the two groups of up and down ones are further distinguished by giving a different colour, say blue, or red and black striped, to one of them. Furthermore, where the number of levers is great, there is painted down the side of each the numbers corresponding to the levers which have previously to be set to enable this individual one to be moved.

This system of locking, as also with the spring eatch motion, has been largely applied in England, and many very interesting examples exist in the large Metropolitan stations, and at important junctions, especially on the London and North Western Railway, at Crewe, Chester, etc.; the former of the junctions requiring no less than three signal huts for its protection, one with 72 and the two others containing 64 levers each.

Mr Anderson's apparatus differs much from either of the preceding: it is based on the principle of the Jacquard loom, selecting the point or signal levers, which are to be worked in each position, by means of a perforated selecting

bar, running at right angles to the course of the levers, and generally placed at the back of the frame; this bar is moved laterally by means of a selecting lever into as many positions as there are combinations of the points and signals. This, situate in the middle of the row of levers, works in a quadrant having notches cut in one side, and which, corresponding to the distance the selecting bar has to be made to travel for each position or combination, serve to retain the selecting lever in those several positions. The selecting lever is connected with the selecting bar by link motion, thus causing the latter to travel to the right or to the left while its own course is backwards and forwards.

The other levers also work in quadrants furnished with several notches each, so that the portion of the quadrant the lever is drawn through may vary with the alterations of temperature; an important consideration where the connections are of some length. To each point and signal lever there is attached, between its pivots and the quadrant, a locking rod, which, extending backwards to the selecting bar, passes through an opening in it whenever the position is such, that it is desirable the backward motion of this particular lever should lock the selecting bar in that position.

The form of these locking rods, as regards the extremity which traverses the selecting bar, varies with the duty each has to perform. If it is simply a round bar, as *h* (Pl. XXXVII, fig. 9), the effect is only to lock the selecting bar, which cannot be moved again till this particular lever is restored to its forward or normal position. If of the shape shown as *i*, tapered at the end on its upper surface, besides locking the bar it determines the priority of movement for itself over such a one as *h*, for supposing each of these, when moved against the selecting rod, finds it a little too low for them, then *h* would not be able to enter at all; but *i*, thanks to its tapered end, could do so, and in its passage through the selecting bar would gradually raise it on to its own upper surface, and so place it at a level convenient for *h* to enter. Should it be still further desired to require a certain order to be observed both in locking and in unlocking certain points and signals, a form such as *k* is adopted, serrated sometimes on the under and sometimes on the upper side according to circumstances; since its tapered extremity secures its being moved before *h* or *i*, then the latter, finding the selecting bar raised sufficiently to admit its tapered extremity, is next passed through, not merely admitting *h* by again raising the selecting bar, but also by the same act engaging it in one of the notches of *k*, which is thus held fast. To release the selecting bar the reverse order, that is *h*, next *i*, and then *k* must he necessarily observed.

It is usual to place on each side of the selecting bar two guide bars, running parallel with and close to it, and having perforations similar to it, to assist in

guiding the locking rods; these guide bars may be further made use of to assist in locking, and in determining the order to be observed therein, by being made to engage in the serrated notches of the locking bars, in the same manner as already described for the selecting bar.

In order to simplify the working of the apparatus, and to prevent loss of time on the part of the pointsman, there is engraved upon a brass plate, at the extremity of the quadrant of each lever in front of it, its number in order and its situation on the ground. Furthermore upon the quadrant of the selecting lever there is fixed an index plate, shown in fig. 8; the notches on the right hand side being the positions into which the selecting lever is thrown, the inscription along side of each giving the numbers of the points and signals to be worked to effect the position, while on the opposite or left hand side are shown the direction of the trains requiring each of those positions. This method of marking the operations to be executed is so simple, that a stranger may almost perform them.

Another advantage of this apparatus lies in requiring but few alterations, should it be required to insert any additional points or signals; as, besides the additional lever and its locking bar, merely an extra hole is required to be punched in the locking bar in certain of its positions or combinations.

These apparatus have been extensively applied in Ireland; in England, on the Lancashire and Yorkshire railway; and in Wales.

The invention of Mr Brady, the engineer of the South Eastern Railway, consists in the separation of the signal from the point levers, dividing them generally into two distinct classes, and in assigning to each division a different form of connection; but of such a description, that any member of one class, by applying its own connection against that with which a certain member of the other is provided, may effectually lock the latter in the position it then holds, and prevent its being moved till released by the former.

The members of the signal lever class, as shown in figure 11, have jointed to them, a short distance below the quadrant through which they move, horizontal bars *l* carrying at certain distances curved links *m* having their upper extremity jointed to the bar and their lower pivoting in a socket fixed to the floor; the action of these links is thus always parallel with the lever to which they are attached.

The second division, or point levers, see fig. 11, have jointed to them near to their pivot a link, or links, which connect with an arm *o* keyed on a rocking shaft, *p*, or with several shafts as required, which run longitudinally parallel with the line of levers, and are arranged behind or before them, or both, according to circumstances. These rocking shafts, supported on shoes

fixed to the floor, also carry other arms or locking arcs *q*, where required. Each of these is placed immediately behind a curved link of the signal it is designed to act upon, so that the backward motion of the point lever causes, by means of the revolution of the rocking shaft, the locking arc to move from a pendant position up and forward through a quarter of a circle; thus bringing itself into a horizontal one in front of the rocking shaft, and pressing hard against the curved link of the signal lever which it effectually locks and prevents from being moved backward.

It must be borne in mind, that the action of the curved links *m*, attached to the horizontal bars of the signal, is in direction with that of their lever, whereas that of the locking arcs *q*, on the rocking shafts of the point class is opposed to that of the lever to which they are connected; thus the effect of the opposite motion of each division is that one forestalls the other, and its movement prevented by the pressure of the former against the latter.

Should it be required by means of a signal lever to lock one or more point ones, this is effected by the backward motion of the curved link of the signal pressing against and retaining in its pendant, or normal, position the locking arc of the point one, and so preventing the latter from rising up into its forward one.

In this, as in the other locking systems, the numerical order of the levers, as well as the position on the ground of the signals or points which they work, may be indicated to the signalman by means of brass plates fixed at the ends of the lever-quadrants.

These apparatus are in use, and give every satisfaction at some very important metropolitan stations in London, as well as at others of the South Eastern railway.

Figure 12 of Plate XXXVII shows a cross section of Mr Skinner's invention. It may be thus briefly described. The lever in its passage through the quadrant causes a round shaft *r*, attached to it by means of a link or otherwise, to revolve; this last carries keyed upon it as many notched bars, similar to *s*, as there are levers requiring to be locked by it, each of them having a small pin projecting from the side onto which the notch of the bar drops and holds it fast, until the first named lever by the revolution of the shaft *r* lifts up the notched bar.

In order to make allowance for expansion and contraction in a lengthened connection with a distant signal and requiring its lever when moved to pass through a greater or lesser arc of the quadrant, already furnished for this purpose with several notches, similar notches are introduced into the serrated bar, so that the one in the bar corresponding to that in the quadrant takes

hold of the projecting pin in the side of the lever to be locked. This apparatus is used extensively by the Great Western railway.

In figure 13 of Plate XXXVII is seen an ordinary junction on a double line of railway; while figures 3, 4, 6, 7, 10 and 11, show the number of levers and the general arrangement required for the working thereof on the several systems of Messrs Saxby and Farmer, Anderson, and Brady. It may also be noted how the four different positions, or combinations of points and signals for "Up main" line, "Down main", "Up branch", and "Down branch", are represented in the first named system by the four tiers of horizontal sliding bars and their complement of locking plates (figs 3 and 4); in Mr Anderson's by the four notches on the right of the index plate for the selecting lever (fig. 8); and Mr Brady's by the four rocking shafts (fig. 11).

Other forms of locking apparatus exist, but to enter into them all would occupy too much space, especially since those already described are the most extensively used.

Locking apparatus for level-crossing gates. — We may here briefly mention a subject which is closely connected with the one just described; namely, the simultaneous action of road-crossing gates with the signals protecting them, together with the means of locking them both in any desired position, thereby ensuring safety to the trains and to the road traffic. From the several methods for effecting these objects we will select two; one adopted by Mr Vignier, and similar to his system for locking points and signals, the other the invention of Mr Lea, and manufactured by Messrs Saxby and Farmer.

In Mr Vignier's system each pair of gates when closing the road is retained in place by means of the outer end of a rod pressing against them at the point where they come together; these two rods are continued in direction at right angles to the line, and are connected by means of a bell-crank lever to another rod, which is worked by a handle lever, placed where most convenient. This working lever has jointed to it near to its fulcrum, exactly as in Mr Vignier's system for points and signals, a horizontal sliding bar, working in front of it. The bar is pierced with two locking holes, through which round bolts are shot by the action of the levers of the two distant signals for the up and the down main line, whenever each indicates that its own line is clear.

Thus, not merely the simultaneous release of the four gates closing the road is ensured, but also that this shall not take place until not only one but both of the distant "danger" signals of the "up" and "down" main lines have been exhibited.

The gates themselves are opened by hand; the rule generally in France is

that they turn outwards, that is towards the road, and not across the line as in England. The delay in opening the gates, requisite for the gatekeeper to pass from the releasing lever to each pair of gates, is, says Mr Vignier, beneficial; inasmuch as it allows any train, which happens to be within the distant signal, when it is set at danger, time to pass over the crossing before the gates leave the road free.

Lea's apparatus for connecting the four gates of the crossing together consists of two levers of the first kind (if a double line of way, but of one only if single), running across the line of rails and down the centre of the road; each lever extending from the edge of the railway half way across it, where they meet in the middle of the line, and their ends are connected together by means of a slotted eye and pin. While to the outer extremity of each lever is fastened a rod at right angles, which connects it with the heels of the two gates on that side of the line; furthermore to the outer end of one of the levers is attached a rod communicating with a hand lever, placed where convenient, and by the action of which all four gates are worked simultaneously. This hand lever is also connected with a distant signal on the line by a wire, in such a manner that the action of opening the gates to the road sets this signal at danger, while that of closing them shows the line to be all clear.

For the further protection of the trains there is at the crossing itself another signal, the hand lever of which is placed close to the one working the gates, and connected with it is a rod which, when it shows the line to be clear, is shot through an aperture and blocks the passage of the gate lever to the position it assumes when the gates are open; and similarly, when these are open, a bolt connected with their lever closes the aperture to the crossing signal lever and prevents its being placed at "line clear". So that whenever the gates are open to the road there must always be two signals on the line at "danger", a distant one and another at the crossing itself; and likewise, when the signals show the line to be clear, the gates are locked and it is impossible to open them.

To retain the gates in the position given to them four stop boxes are used; two in the centre of the road, outside of and alongside of the line, corresponding to the position each pair of gates assumes when the road is closed, and the two others in the middle of the line to catch the foot of each gate when the line is blocked. Each box contains a fixed stop on the outside, and towards the inner side, at a distance equal to the thickness of the gate, a pair of moveable stops, which may be lowered by the action of a lever, rendered self acting by means of a weight attached to it, thus causing them to rise again as soon as the gates have passed over them.

To ensure the simultaneous action of the stops the four boxes are connected by rods to a central cross shaped lever, placed horizontally; and to the outer end of one of the boxes is attached a rod from a hand lever, which is thus able to work the whole four boxes in pairs as required.

§ XVI. — Details of construction of points and crossings.

273. Though we have dwelt at some length on the subject of points and crossings, yet so far only the general conditions under which they ought to be placed have been considered. We must now study somewhat more closely these apparatus, which, though already the subject of many improvements, are still open to many more. These details shall be abridged as much as possible; but, should they however sometimes appear too minute, the reader must kindly remember that this subject affects in a very high degree the economy and the security of the circulation.

274. *Crossings.* — The crossing-point and the wing-rails ought to be firmly connected together. The care with which the level of each has been regulated (257) is soon counteracted by their own wear and by that of the tires; but precautions must be taken at least to prevent unequal settlement adding to the effects of inequality in wear.

Endeavours have often been made to obtain a perfect connection by fixing the crossing point and the wing-rails down upon a wrought or cast iron bed-plate, to which they are connected either directly by rivets with their heads countersunk, as on the "Berlin to Anhalt", the Rhenish, etc., railways; or else, as in the crossing of the Eastern of Belgium (Pl. XXIII, fig. 43), by wedge shaped strips *f*, *f*. The bed-plate, being bolted or spiked to the sleepers, allows the whole to be quickly replaced; but this advantage, as well as that of the close connection of the parts of the crossing, would not compensate for the imperfection arising from the use of rivets, which soon become loose under the influence of vibrations, consequent upon the mass of the whole being too slight.

275. *Cast crossings in a single piece.* — For some time before these were tried, a more radical solution of the question had often been used, which consisted in making in one piece the point of the crossing the wing-rails and a portion of the running rails. These cast crossings were formerly much used in Belgium and in Germany, particularly in Bavaria. Almost abandoned for some time, these hardened cast crossings "Hartguss" (*) have again reappeared

(*) It is well known that the hardening resulting from chilling during casting is not the only

in Germany for some years, thanks especially to the exertions of two well known manufacturers, Mr Ganz, of Buda, and Mr Grusen, of Buckau, near Magdeburg.

It is certain that these metals, free from air bubbles and presenting regularity of hardening, often afford very good service. On the Central of Switzerland the solid "Ganz" crossings lasted two years; where the ordinary iron ones in several parts had to be replaced at the end of some months. Twelve crossings from this foundry, which were laid down on the Saarbrück line in 1861, were in very good order four years afterwards, though iron ones with steeled crossing point had lasted but three or four months. Crossings in "Gruson" metal are in much esteem, in the duchy of Baden, where also those from the engine works at Carlsruhe give much satisfaction; in Bavaria on the State Railways; in Prussia on the Eastern line where they have been in use largely for some years back; on the Rhenish lines, the Saarbrück, the Rhine and Nahe, the Berlin Potsdam and Magdeburg, the Aix Düsseldorf and Ruhrort, the "Charles-Louis" (Gallicia), the Magdeburg and Wittenburg, etc. The Rhenish railway has also used for some time, and so far successfully, hardened cast crossings from the old royal foundry of Sayn, now belonging to Mr Krupp of Essen.

Elsewhere however they give less satisfaction. The Upper Silesia, Lower Silesia and la Marche, Berlin-Anhalt, and other railways have been somewhat disappointed with them; the cast metal seems in fact but poorly suited for crossings which are run over at great speed, even on double lines of way, where the trains ordinarily pass over the crossings from heel to point or in the most favourable direction for their preservation. Similar results followed from the trial of some "Gruson" metal crossings in France on the Eastern and on the Western railways.

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method in use to give the surface of certain castings the degree of hardness and of tenacity which they require. The process often consists in actually steeling them, that is to say in a partial and superficial decarburisation of the casting, by heating it highly in a species of oxidizing cement, generally composed of iron ore. It is by this means that Messrs M'Haffie Forsyth and Miller of Glasgow produce their malleable and highly resisting cast metal. In France Mr Dalifol uses the same process, but only with castings of small size.

In Germany, despite the secrecy with which everything connected with these malleable castings is surrounded, there is little doubt but that expedients of this kind are resorted to.

Partial decarburisation may also be obtained, but then it is throughout the whole pieces, by recasting it with a suitable proportion of iron in small pieces. Mr Grüner (see article on "Steel and its manufacture" in the "Annales des mines", 1867, vol. XII, page 297) considers it more than probable that the crossings made from "Hartguss" or from "Gruson" metal are obtained by this reaction.

The smelting furnaces of Beulac in the Landes furnish the Southern of France railway with crossings cast from a mixture of ores treated with charcoal; they wear well, but they are not placed upon the main lines.

The French foundry of Torteron, which has acquired a well deserved reputation, as well as the ironworks of Commentry, of Audincourt, etc., naturally endeavoured to create a new market in the manufacture of cast crossings; with however but partial success.

The weak parts of cast crossings are especially their extremities; the point and also the wing-rails generally stand pretty well against the immediate action of the rails, it is however more particularly at their junction with the main rails that the wear takes place. The pieces ought to be longer and more massive to diminish the violent vibrations to which they are subjected, despite their connection with their supports and with the rails, whenever the speed is considerable; to effect this however the operation of casting would be more difficult, more costly, and the quality of the result would be more uncertain.

The method of connecting them with the main rails differs. In the crossings made by Mr Gruson for the Eastern of France, the rails clipped by the casting are tightened up by a wedge B B′ (Pl. XXIII, figs 29 to 32), and by a bolt with a pin through it, *t i*, *t′ i′* : this method is simple, but hardly seems to ensure a sufficiently close connection.

276. On the Thuringian railway mixed crossings are used, composed of a single cast piece, rivetted onto a wrought bed-plate; this arrangement would be, it is said, more durable than the former, and more economical inasmuch as it allows the weight to be reduced. Unless however the crossings are run over at a slow speed, lightness is not an object to be sought after.

In the new crossing of the Taunus line, the bed-plate has only the point cast with it; the wing-rails are separate and of wrought iron. Thus either one or both of them may be changed; an important point when, as is often the case, they belong to lines having a very different amount of circulation from one another. The hardened point, thus well protected against concussions from the wheels by wing-rails, changed in good time, has acquired an increased durability.

The bed-plate, 4′·6″ long, is fastened to three sleepers by nine pegs, the heads of them pressing by means of small cast blocks upon the outside edge of the foot of the wing-rails, of which the inside edge fits into hollows formed in the main casting. Fishplates with four bolts connect the point with the main-rails branching from it.

Mr Hartwich's crossing presents some analogy to the foregoing. The point proper is a casting raised from the bed plate the depth of the rail, less its foot, and fixed on one side to the wing-rails, and on the other to the main-rails, by two tiers of horizontal bolts. The guard-rails are connected to the main-rails next to them by two rows of bolts, with distance collars to each.

277. *Cast steel crossing in one piece.*— Against the advantage of having the crossing in one piece, there is the serious inconvenience of necessarily laying the whole aside on account of the wear of one part only. Such crossings can therefore be advantageously constructed only of highly resisting materials, very constant in their nature, subject merely to slow and inevitable wear, and free from the chances of breakage. Cast iron, despite the skill acquired in making castings, affords a result too often capricious and unequal in quality. The change which has taken place latterly in the production of cast steel now places at the disposal of engineers a material upon which they can count with greater certainty. It is true, that the engineers of the Rhine and Nahe line, in their inquiry in 1865, placed on the same footing the hardened cast crossings of "Gruson" metal with those of cast steel from Bochum; but will this equality, though apparently real up to 1865, continue under a more extended test?

Though fully acknowledging the high quality of cast iron crossings, the railway from Magdeburg to Leipzig declares, as far as concerns itself, that cast steel crossings, though double the price, ought to be preferred to hardened cast iron ones. The choice between two materials, differing both in price and in quality, may and ought to vary from one case to another; it is a question of traffic and of speed. Also is it certain that good hardened cast iron is better than bad steel; but, setting aside exceptional qualities and merely taking medium ones, it cannot be denied that cast steel in itself, and without taking the price into consideration, is preferable to hardened cast iron. On the other hand it has become much more economical to cast the crossings, since that multiplicity of types, imposed for a long time by a pretended geometrical exactness, has been abandoned, and that two only, ordinarily 5°·30′ and 7°·30′ (262), are considered sufficient.

If the majority of the uses to which cast steel is put imperatively require it to be hammered, by which process alone can body be given to it, the operation can nevertheless more readily be dispensed with for certain purposes by this material than by wrought iron; which requires the hammer to purify it and to expel its dross. Steel may be treated similarily to cast iron; coupled however with the special difficulties which arise from the high temperature

required to be maintained, and in moulds which had best be of a highly refractory mixture. It may then be hardened like cast iron by being chilled when cast.

One of the difficulties lies in the formation of bubbles. They ought to be avoided not only in castings but also in the ingots which have to be hammered and shaped, since the action of forging merely crushes the blisters without welding together the faces which are brought into contact.

In England this result has been sought to be obtained by imparting to each ingot-mould, after the metal was run into it, a rotatory movement round its own axis; thus collecting the gases in a single central bubble of sufficient strength to burst itself: the speed however is but slight, about five and twenty turns per minute. In France also this expedient has been adopted at the iron works of Imphy (Nièvre), and the result there has given satisfaction; other highly skilled manufacturers on the contrary do not acknowledge, that there is any efficacy in this process, which besides would be almost inapplicable to the majority of castings.

" We are aware" say Messrs Petin and Gaudet (*), who were consulted by the author upon the subject; " of but one method of preventing air bubbles; viz to weight the " casting heavily by taking care to retain a large amount of residue. This method " however has the effect of considerably enhancing the net cost, and its result in the " present case, the manufacture of crossings, would be to render the price un- " marketable.

" We have tried a rotatory movement given to the ingot moulds; in addition to " the fact that this movement cannot in practice easily be imparted to the casting " moulds, we can assure you that, even applied to ingot-moulds, this method affords " *absolutely* no appreciable and regular result.

" Theoretically in general, the greater the surface of the mould in proportion to " the volume of the casting, the more chance there is of blisters. They may be " diminished by a greater or less pressure upon the moulds, or by introducing a " strong proportion of cast metal in the mixture for the crucibles; the result however " is but a bastard metal, which no longer possesses the properties of steel."

At the River Don Works, Sheffield, belonging to Messrs Vickers and Co, the weight of the residue amounts almost to that of the casting, particularly if this be not large. It is moreover found necessary to continue the supply of metal lest there form, besides the bubbles proper, a central cavity caused by the large amount of total contraction which the steel experiences in consequence of its high temperature. The creation of blisters is even more successfully overcome by running the metal into iron moulds under pressure.

(*) Letter dated June 26th 1867.

This often becomes very great; according to Mr Gruner (*), Messrs Revollier and Bietrix, at Saint-Etienne, work up to 500 and 600 atmospheres.

278. The products known now-a-days in commerce, and especially with railways, as cast steel are the proceeds either of the crucible, or of the Bessemer converter; or, though up to the present in but small quantities, of the reverberatory furnace.

The common denomination of *crucible-cast* steel is applied to products, which in fact differ as much in their mode of manufacture as in their quality.

Under this head is included, 1st cemented steel cast from the crucible; 2nd puddled steel cast either from the crucible, or even from the reverberatory furnace, and then only passing through the crucible in order to be cast, as at Bochum; and 3rd of steel which has been formed in the crucible itself by means of suitable mixtures, particularly of wrought iron, and of cast iron of a special quality. Too much importance must not therefore be attached to the exact name of the mixture; as large establishments, repudiating at least apparently, Bessemer's great discovery, let it be well known that all their steel is crucible cast steel; nor must it hence be concluded, far from it, that their products are equal to the old and classic method of cementation and of fusion in the crucible.

At Bochum the charge in the puddling furnace consists of a mixture of English Cumberland hæmatite pigs together with those from Nassau, with an addition of $\frac{1}{10}$ of "Spiegel". When the balls are hammered, the blooms pass to the roughing rolls, and the bars thus formed are cut up with shears into fragments weighing from $\frac{1}{4}$ to $\frac{1}{2}$ a pound. Fusion takes place principally in the crucible; and, though for only a small quantity so far, in the reverberatory furnace. Each crucible receives about 66lbs of steel, which when cast does not occupy at most more than half of it; the crucible is then emptied into another, unless with very small pieces: thus about 1cwt is held by each crucible, itself emptied into an ingot mould previously heated, capable of containing the necessary quantity of metal, and provided with a hole at the bottom, having an iron stopper to it.

In fusing by means of the reverberatory furnace the difficulty has been, it is needless to say, to obtain a bottom sufficiently refractory; and apparently this has been successfully overcome. The steel is not run off straight into the ingot-moulds, but into other crucibles similar to those used to fuse it in; this

(*) See page 245 of work already quoted.

intermediate operation, special apparently to the peculiar arrangement of particular works, will probably disappear with the more extended use of the reverberatory furnace.

M^r Mayer, the director of the casting department at Bochum, has overcome in a very satisfactory manner the different difficulties which presented themselves in the casting of steel. The castings from this establishment are sound, free from bubbles, and very homogeneous.

Soft steel very rapidly destroys the crucibles; at Stourbridge they last at most but two operations. Mess^rs Vickers of Sheffield have with much advantage introduced the use of plumbago in the composition of their crucibles. The worn out crucibles are ground up, and sufficient clay is added to render the mixture plastic.

The requirements of a large consumer, like a railway, are a sufficiently good quality at a moderate price; and, with the saving which it effects in its manufacture, Bessemer steel may quite equal that which is crucible cast. Mess^rs Vickers manufacture crucible-cast crossings, formed we are told of Swedish iron; but their price is much too high. The Eastern of France paid over £39 per ton for some it got in 1865; or at the rate of £18, 12s. per crossing, weighing 9^{cwt}, $1\frac{1}{2}^{qrs}$ (Plate XXIII, figs 17 to 21). Bessemer steel is much less costly, and probably nearly as good.

In this form of crossing, as well as in the one shown in Plate XXIII, figures 22 to 28 and made by Mess^rs Petin and Gaudet, the connection with the stock-rails is by fishplates: instead of dovetailing the ends of the rails as in the crossing already described (275), the casting carries at each end a projecting piece B, B′, which is grasped between the two rails; a couple of fishplates with two, or better still four, bolts secure a closer connection than by dovetailing with a wedge as in the cast-iron crossing.

The crossings supplied by Mess^rs Petin and Gaudet to various companies, and especially to the Western and to the Southern of France, are crucible cast and not Bessemer steel; their net price being £36 per ton. The double-headed type of the Western and the Southern railways, which has been tried, though only as an experiment on the Suburban line round Paris, as well as upon the Badajoz one, etc., weighs $5\frac{3}{4}^{cwt}$ for the 5° 30′ crossing, and $5\frac{1}{2}^{cwt}$ for the 7° 30′ one; fitted up with chairs, fishplates, and bolts complete, they were delivered at Paris to the Western R^y for £15 each, and to the Southern line at Bordeaux for £15, 15s. each.

The crossing for a Vignoles rail line weighs 7^{cwt}.

A wish to utilize more fully a material relatively high in price has often led to the construction of cast steel crossings which are symmetrical or double-

faced; these are shown in Plate XXIII, figures 10 to 16 being for the double-headed rail, while figures 33 to 38 are for the Vignoles one. The former form, though seeming to afford the two advantages of lightness and of capability of being turned, appears to have answered but poorly to the expectations of its advocates. The crossing rests upon the sleepers by means of the two chairs, K, K, and of the two fishplate-chairs, E, E (figs 33 to 38), which at the same time connect it with the stock-rails. The extent of bearing surface upon the supporting chairs is moreover too limited; and breakage is much to be dreaded if the flange of a tyre-worn wheel should come to bear upon the unsupported portion of the bottom of the grooves, where the thickness of the metal is too little. In fact the crossing is as a whole wanting in massiveness.

The double-faced crossing for the inverted ⊤ rail made by Mess^rs Petin and Gaudet weighs only $6\frac{1}{4}$ cwt, or $\frac{2}{4}$ cwt less than their single-faced crossing. Its connection with the stock-rails by means of fishplates with four bolts, *t*, *t*, *t*, *t*, appears satisfactory.

In fact, in spite of the success which symmetrical crossings have obtained upon some German lines, in England (on the Metropolitan among others), and in the United States, a conclusion has been pretty generally arrived at upon this point, that cast steel is very well adapted to crossings in one piece, but that with it symmetry and returning must be abandoned.

279. M^r Clerc, an engineer of the "Ponts et Chaussées" in the employ of the Western of France Railway, has introduced on that line Bessemer steel crossings, hammered and planed (Pl. XXIII, figs 44 to 46).

" In order to obtain " says M^r Clerc in a letter dated July 16^th 1867, " a sufficiently " homogeneous metal, the pieces ought to come from an ingot which has been " reduced by being hammered to one third of its original thickness; the steel ought " to be of a hard quality. The ingot while hot ought to receive the external form " of the crossing; its principal faces are parallel, and upon one of them are cut by " means of the planing machine the grooves for the passage of the flanges. "

The connection with the stock-rails is formed by cast-iron fishplate-chairs with four bolts *t*, *t*; each pair of these chairs being fixed down upon the end sleepers by the screws S, S (fig. 46). The block of steel not being, as with the preceding types, provided with external lugs *c*, *c*, the two screws fastening it to each of the intermediate sleepers are placed at the bottom of the grooves, and let into them so that their heads are flush with the bottom of the grooves (figs 44 and 45).

The 5° 30′ crossing in the rough weighs nearly 8^{cwt}, and when planed $6\frac{1}{4}^{cwt}$, its cost is £ 14·8·0, of which the details according to Mr Clerc are :

Crossing in the rough (Imphy).	8^{cwt}	at 24^s/ per cwt.	9·12· 0
4 Cast-iron fishplate chairs.	$2\frac{1}{4}^{cwt}$	at $\frac{3}{4}^d$ per lb.	» 15· 9
2 » » wedges.	26^{lbs}	at » »	» 1· 7
8 Bolts with nuts and washers.	20^{lbs}	at $1\frac{1}{2}^d$ »	» 2· 6
			10·11·10
Workmanship; planing, fitting and fixing.			3·16· 0
			£ 14· 8· 0

It is difficult at this price to believe that this system is economical, even while making large allowance for the advantage, which Mr Clerc properly insists upon.

" A great advantage of these crossings," he says " and one which considerably " diminishes their expense, is that when worn they may be refaced, as with wheel " tyres, at a slight expense; thus producing an entirely new crossing. How many " times these crossings may thus be renewed depends upon the original thickness " given to them. If made 8″ deep, it seems to us, that they may be refaced two or " even three times. "

Merely the action of reheating and of hammering does not justify so high a price as 24^s/ per cwt for the crossing in the rough. If reduced to a reasonable price this system might be more extensively used.

The casting has on its side economy and superficial hardness resulting from being chilled; if however the hammered and planed crossing is inferior to it on these two points, the beneficial action of the hammer and the facility of compensating by an inexpensive process for the effects of wear and of alterations in form are of undoubted worth; especially when treating of delicate forms, and the wear of which ought, unless under serious inconvenience, to be retained within narrow limits.

About three hundred crossings of this kind occur on the Western of France line, and so far they have worn very well even at the most heavily worked points. However this experience, extending no further back than the end of 1866, cannot yet be looked upon as conclusive.

280. Cast crossings, whether in one piece, or formed of several fastened down to a bed-plate, are in fact up to the present but little used except on a certain number of German railways. Compound crossings composed entirely of the stock-rail, excepting a special piece, the point (and not always this, as will shortly be seen, 281), are much more widely used. But even though the

traffic is but feeble, it is generally acknowledged, that with pieces which are so hardly worked a special material offering a greater resistance than the ordinary rails is required; thus weldings of steel, wrought iron cemented by the "Leseigneur" process, and puddled steel, all tried with more or less success, generally now give way to Bessemer steel.

The point ought to be connected in a manner absolutely invariable to the stock-rails branching from it and to the wing-rails, which ought to be so also with the rails with which they join. With the general form of rail this last condition is naturally fulfilled by the ordinary fishplates. It is also by fishplates that the point piece is connected with the rails branching from it when, as on the Northern of France, it is simply cut off at the heel end (Pl. XX, fig. 7); it then has towards the extremity a hollow on each side to receive the fishplates. Towards the tapered point it carries at either side a forged projection, the whole completely filling up the space between the wing-rails, and fastened down vertically by two bolts. The whole of this part, the point and the wing-rails, rests upon a strong cast bed-plate (fig. 8), and two strong bolts crossways retain the wing-rails pressed against the point.

In other cases, as on the Orleans line with a double-headed rail, the cast steel point carries towards its heel a species of tail *l*, *l*, which, entering between the rails branching from it, is kept pressed against them by bolts (Pl. XXIII, figs 39 to 42); towards the other end it has simply the form shown in figure 40, and is maintained in its place by a triple chair.

On the Eastern of France in the Vignoles crossings in use up to the present (Pl. XXIII, figs 1 to 9), both methods just mentioned for connecting the point with the rails branching from it are employed conjointly; at its heel the point-piece has the interior projection *l* (figs 5, 8 and 9) as well as the outside fishplates θ, θ (fig. 1); while the point, like the stock-rail retains its foot *p*, *p* (fig. 9), which projects beyond the tapered end *m* in order to receive the screw *o*. Two horizontal bolts *f*, *f* (fig. 9), with distance pieces connect the wing-rails with the point; wrought iron bed-plates ν, ν (fig. 1), which give an inclination of $\frac{1}{10}$ to the rails, are placed at the tapered end of the point, as well at its heel, and at the summit of the angle in the wing-rails. The point-piece is of wrought iron, cemented and hardened; the wing-rails are of Bessemer steel, and the rails branching from the point are of ordinary wrought iron.

281. These arrangements have been simplified (Pl. XXII, figs 8 to 23) by no longer making the crossing point a special piece; it is formed by the continuation of one of the rails *p*, branching from it, and connected by three

bolts t, t, t, with the other one q, which is suitably tapered and reduced in height, and fashioned towards its extremity somewhat like a fishplate-chair (figs 14 and 15). The old crossing points of wrought iron were also formed of rails connected together; but the new arrangement is far preferable, as it prevents all difference of level between the two rails, while at the same time the bolts t, t, t, remain only in tension. It is scarcely necessary to add, that all the hardly worked parts of this crossing should be Bessemer steel rails.

Of the three bed-plates ν, ν, ν (Pl. XXIII, fig. 1), in the old crossing only the one at the point itself is retained (Pl. XXII, figs 10, and 20 to 22). Two bolts θ, θ', with distance blocks K K', keep the point and the wing-rails together (Pl. XXII, figs 10, 13 and 16). These arrangements are about to be applied to the 5° 30′ and to 7° 30′ form of crossing, the only ones in use on the Eastern of France system.

282. Some railways, which have not yet acquired confidence in steel, still make use of wrought iron, but of a special quality, for the crossing point at least. Thus in France at the iron-works of Fives, in the "Département du Nord", wrought iron crossing-points, made with charcoal iron, and hardened, are made for the Russian railways. Elsewhere, preference is given to puddled steel. This is the case on the Lyons line; but solely on account of the method of manufacture of the crossing point which is formed of two rails welded together. The causes of this preference are explained in the following note, which Mr Delerue, the engineer in chief of the line, has kindly placed at the disposal of the author.

"The point-piece of our crossings is formed of two portions of rails welded "together very nearly along the line which bisects the angle. Inasmuch as no "means have yet been arrived at by which a proper weld can be made with either "Bessemer steel or with cast steel, we have been obliged to employ puddled steel, "in spite of its high price and notwithstanding that the wear of this material upon "the line gives far inferior results than do the two other kinds of metal. It may "also be noted, that in our crossings the wear of the point-piece is tolerably slow, "as it is protected by the wing-rails, which do the principal work and wear out in "about half the time, though made of cast steel."

283. The Eastern of Bavaria has also applied on a large scale the combined-point arrangement in puddled steel shown in Plate XXII, figs 26 and 27. These crossings present certain peculiarities which deserve to be described. The point, *m*, falling rapidly is left by the wheels as soon as they begin to bear on the wing-rails. Upon them therefore is thrown the brunt of the wear; the following simple and economical method of repairing them has been tried.

The worn part is planed down, over a length of from 2 feet to 2 feet 6 inches, according to the angle of the crossing, to the form *abc* (fig. 27); a cast-steel covering piece *amnp*, much hardened at *amn* is then fitted to it. Old cast-steel wheel-tyres are used for this purpose; as their shape is suitable, the flanges forming the head *amn*. Many hundreds of crossings protected in this manner are working satisfactorily.

Mess[rs] Van der Elst, of Braine le Comte in Belgium, have (Plate XXII, figs 24 and 25) sought to combine perfect connection among the parts with facility in dismantling and in partial renewal. The point, either in wrought iron, cemented, or in Bessemer steel, is provided with a broad foot, and a projection A extending forward to the angle of the wing-rails; it is fixed to two sleepers by the two large bolts and nuts *b*, *b*, and to the stock-rails, as well as to the wing-rails by the tenon *l*, and by the distance-piece bolts *t*, *t'*. The two bolts *t''*, *t''*, tie the bent-rails together. This arrangement rests directly upon three cast bedplates E, E, E, the utility of which is however doubtful.

284. It is not possible to classify in any strict manner the different types of points and crossings just described. The individual choice in each case must depend upon the price, the speed, and, as is always the case, the activity of the traffic; since it is the annual outlay which should be reduced to a minimum.

The following comparative results were afforded by a trial of the various types in the Station at Vienna of the Austrian State Railway.

Points and crossings	with ordinary rails, having the point steeled, lasted. .	2½	years.
—	of puddled steel.	5	—
—	of cast " Ganz " metal.	10	—
—	of Bessemer steel, double-headed, 7 years for each head, or in all.	15	—

These figures must however be taken with reserve, as the comparison did not extend over a sufficient number of each kind to eliminate with certainty the influence of accidental irregularities. Besides to overlook, with the cast-steel double-headed crossing, the special chances of rupture inherent to its form would be to give it an undue preference.

285. The gauge of the line is sometimes slightly diminished at the crossing-point, to prevent the running off of certain vehicles, whose too narrow tyres could not fulfil the condition pointed out in N° 257. Care however must be taken, least by so doing a greater danger be not courted; namely, the concussion against the point of wheels having the ordinary width of tyre. Thus,

for example, it may be seen from Plate XXIV, fig. 39, that (with the following dimensions, gauge of line $4'\,8\frac{1}{2}''$; from guard-rail C to rail A, $2''$; width in the clear beetween the wheel-tyres $4'\,5\frac{1}{8}''$; thickness of the flanges, measured horizontally and at the level of the drooped top of the crossing-point, $1''$) the wheel R, meeting the crossing point, may graze it at a distance of $4'\,8\frac{1}{2}'' - (2'' + 4'5\frac{1}{8}'' + 1'') = \frac{3}{8}''$ only; and this play may become even less by the wear of the guard-rail C. As to the wear of the flanges; that which affects the outside face of the flange of the wheel R increases the play, which is however diminished by any wear of the inside face of the wheel-flange S.

286. *Through-crossings.* — Some foundries, that of Mr Ganz amongst others, make through-crossings of chilled cast iron; each of the crossing sides being formed of two pieces clipped by fishplates. In cast steel Messrs Petin and Gaudet do away with the joint at the elbow (Pl. XXII, figs 1 to 7), though the length of the casting is thereby reduced : this system is however but little used, especially on account of the great depth required by the guard-rails, a depth difficult to obtain in castings, particularly in steel ones.

The stock-rail is therefore ordinarily in form, if not also by its nature, the principal or even the only element of the through-crossing. In the first type in use on the Eastern of France (Pl. XIX, figs 10 and 13) there is nothing else : the two obtuse angles are formed of Bessemer steel $12'\,6''$ bent-rails, as are also the four tapered ones, $9'\,2''$ long each. The guard-rails BB, $19'8''$ long, are in wrought iron and fixed upon chairs giving them only $1\frac{1}{8}''$ of extra height; these chairs have but one jaw to which the guard-rail is bolted. A couple of distance-piece bolts connect together each of the tapered points of the side parallel to the obtuse angle.

These tapered points present a similar arrangement to that already described (257), in connection with the wing-rails and with the crossing-points.

Thus, instead of being cut along a plane parallel to the outside rail, the pointed rail is bent very nearly in that direction; so that its web is not cut away at all (fig. 13). Its head is however not merely reduced sideways, but it is also curtailed in height (fig. 12) so as to withdraw it gradually from the wheels bearing on the outside rail. Another peculiarity to be noted is the twist given to the point-rail, where the tapered portion meets the untouched part of the rail; caused by the fact that the point is vertical, and the corresponding portion of the foot is consequently horizontal, while the rest of the rail has ordinarily an inclination of $\frac{1}{20}$.

The through-crossings of the Northern and of the Austrian State Railway, shown in figs 3 to 9 and 14 to 16 of the same Plate, scarcely differ from the

one just described except in the special arrangement of the guard-rails, named in N° 258; their object being to increase their elevation relatively to the level of the permanent way.

This is in fact a very important condition, and one which, it may readily be seen, is not always sufficiently fulfilled; the guard-rails ought, as already stated (258), to prevent the wheel-flanges not merely from striking against, but also from getting round the points of the tapered rails. In order that the wheel be still guided at the moment that its flange reaches the point, the guard-rail ought at the point where it changes direction, *i.e*, at the elbow C, the commencement of the gap, to be sufficientely raised still to reach that flange at the hinder part of the wheel. AB (Pl. XXIV, fig. 38) is therefore its minimum excess of elevation. If, λ represent the half-gap, *i.e*, the distance from the summit B of the elbow, the limit of the partial guard-rail, to the tapered point; ρ the radius of the rolling surface of the wheel; m the projection of the wheel-flange, then

$$AA'^2 = (2\rho + m - AB)(AB + m) = \left(\lambda - \sqrt{2\rho m + m^2}\right)^2, \text{ since } A'O = \sqrt{2\rho m + m^2}.$$

$$\text{Whence } AB = \rho \pm \sqrt{\rho^2 - \lambda^2 + 2\lambda\sqrt{2\rho m + m^2}}.$$

It is clear however that the *minus* sign alone will suit.

With a through-crossing of 7° 30′, $\lambda = 18''$. If the wheels, at their rolling surface, have a diameter of 3′.3″, and the flanges a projection of $1\frac{1}{4}''$;

then $AB = 2$ inches.

The excess of elevation, first used, $1\frac{1}{4}''$, is therefore quite insufficient.

The wheel is evidently better guided the larger its diameter, the necessary height AB diminishing. With a wheel four feet in diameter, for example, this elevation is only $1\frac{3}{4}''$. Those wheels which it is of most importance to guide thoroughly, the engine ones, are in fact better controlled than those of the remainder of the carriages.

In the new through-crossings of the Eastern of France, the excess of elevation is $2\frac{3}{8}''$, as on the Northern of France and the Austrian State R^y (258); the guard rail is a special wrought iron bar, 7″ deep (Pl. XXII, fig. 29). The chairs are suppressed; as are also the wrought bed-plates (Pl. XIX, fig. 10), those carrying the tapered points being alone retained.

287. *Points and crossings.* — It is only upon those forms which are adapted to the Vignoles-rail, that we shall enter here into any details.

They may be divided into two classes : 1^st Those formed by means of the

stock-rail alone, excepting the switch, every day of more extended use, and made in hammered cast steel; and 2ndly of those requiring special forms of bars. The former is the most numerous, including those on the Eastern (Pl. XXI) and the Northern of France, and on the Austrian State Ry, etc.

The switches must necessarily rest and slide upon cast bed-plates; these have on the outside a sort of jaw, to which the counter-switch rail is bolted. The heads of these bolts, projecting more or less into the interior of the line, form the studs *h* (Pl. XXI, figs 1 and 3), against which the switch rests when its tapered portion is pressed against the fixed rail (265).

In Plate XXI, figures 1 to 8 representing a single point and crossing, and figures 9 to 16 three-throw points and crossings, the switch is formed of a rail, gradually tapering away from the point where it presses on the fixed rail; the web and the outside of the foot alone remaining intact up to the extremity of the point. Besides, however, the outside of the foot and of the head on that side being cut away, the latter is also gradually reduced in height, so as to allow it to rest under the head of the counter-switch rail (Pl. XXI, figs 3 and 4). This is the simplest and most generally used means of protecting the ends of the facing points from the shocks of the wheel-flanges, and also of withdrawing from the action of the tyres all that part of the switch too much weakened by being cut away.

This arrangement however, which effects its object when the system rests on a solid base, would on the contrary augment the evil if this condition is not fulfilled. The switch-point and the rail-head which protects it have their faces in contact inclined to one another (Pl. XXI, fig. 4); so that anything, causing the switch-tongue to rise upwards, at the same time forces it towards the inside of the line. Thus a train facing it strikes it not merely with the tyres but also, which is more serious, with the flanges of the wheels.

In order not to have to return to the subject we shall here describe an arrangement in use on the Northern of France, to prevent the switch-point getting out of level in this way. Stretcher-bars *t*, *t*, *t* (Pl. XXIV, figs 1, 23, and 35), as is always the case, connect the switches together; these rods, three in number with 16′.6″ switches, are jointed near to each end so as to follow the changes in form of the system. The method used on the Northern of France consists (Pl. XXIV, fig. 33) in lengthening at each end the bar nearest to the switch-point. These prolongations *p*, *p* fit into two oval holes, with their greatest length horizontally, in the two counter-switch rails; the switch-points being thus rigidly connected, vertically, with these rails. The joint *a*, at the working lever side, also includes the bent-rod *b*; which is commanded by the lever.

Reverting to the points and crossings of the Eastern of France.

In those now in use (Pl. XXI, fig. 1) the heel of the switch is held in a special, double-jawed, chair; the foot of which gives to the fixed rails an inclination of $\frac{1}{20}$, while the foot of the switch is kept horizontal by it. A couple of bolts fasten the whole together. A cast distance-block, clipped between the two fixed-rails, ensures sufficient freedom to the switch for the slight movement of its heel; kept in place by the bolt which passes through it and the jaws of the chair.

In the new types on the same line (Pl. XXIV, figs 17 to 23) this complicated form of chair is done away with. The heel of the switch rests and slides on a simple bed-plate chair, *g*, *g* (figs 17 and 18); and is connected to the extremity of the rail *k* by fish-plates *e*, *e*; an arrangement which has been long in use. The end of this rail is slightly unsupported, in consequence of its own inclination and of the bed-plate of the chair being horizontal (though it is inclined underneath the outside rail *l*). The joint of the switch is therefore placed just outside of the edge of the chair.

This connection of the vertical rail with the horizontal switch affects somewhat the form of the two fishplates; which are not exactly alike the one to the other, and differ also from the ordinary fishplates. The slight alterations in the form of the fishplate, due to relative projections of the switch and of the rail, are shown in figs 19, 21 and 22. The parts sectioned darkly are those cut away in the fishplates of the left-hand switch-heel (taken as facing-points), and those sectioned lightly are those belonging to the plates of the right hand one.

The points and crossings on the Northern of France only differ from those on the Eastern line by the improvement just mentioned and by a peculiarity in the fishplates, which are turned up like a horse shoe for the switch to rest against. This arrangement is applied to the fishplates both of the switch and of the counter-switch rail, which last has its joint corresponding the unsupported part of the switch (Pl. XXIV, figs 32 and 33).

288. *Three-throw points and crossings.* — These are, as already stated (267), an extension of the simple point and crossing; and the principal details of construction are common to both kinds. Figures 9 to 16 of Plate XXI, the form in use on the Eastern of France, are sufficiently easy of comprehension to render it unnecessary, after what precedes, to enter into further details.

This type was besides included in the revised and simplified forms of single points and crossings, which recently took place. The special heel-chairs were replaced by simple sliding ones, with fishplate connections and slightly un-

supported joints (Pl. XXIV, fig. 24). The third fishplate bolt (from the switch-point) is provided with an end stop *h*, and with a distance piece *m*. The short switches have also been lengthened, so as to reduce the extra width of the line at the points (267); from 11'.9" to 14'.7", or only 21" less than the long switches. The extra width is thus reduced from $2\frac{3}{8}$" to 1"; this might be still further decreased, but with a width of 4'.10" running off the rails need not be dreaded.

" Notwithstanding these improvements ", says Mr Ledru (*), " three-throw points " and crossings ought only to be used where absolutely obliged through want of " space. As each one of them costs in fact more than two sets of single points and " crossings, since with the former one additional crossing is required."

289. *Points and crossings with special forms of bars.* — On some lines, the Paris and Mediterranean system for example, with inverted ⊤ rails is used an unsymmetrical steel rail, which, when the foot is horizontal, having an inclination of $\frac{1}{20}$ (Pl. XXIV, figs 25 and 30 to 33). The switches thus have an inclination similar to that of the stock rails; and the counter-switch rails are like the former set in chairs having the foot quite horizontal. The use of this special rail appears to give a theoretical rather than a real advantage.

The heel-chair for single points and crossings (Pl. XXIV, figs 26 and 27), and for triple ones (figs 28 and 29) is a bed-plate with the edges but slightly raised, and its bed horizontal under the switch and the counter-switch, but inclined $\frac{1}{20}$ under the two stock-rails. The feet of these rails and of the switches are kept together by a sort of horizontal joint plate, *g*, *g*; similar to those for ordinary joints, still in use on seme German lines (66, 65). A non-symmetrical rail has been similarly treated on the central portion of the Orleans Ry; the switches and the counter-switch rails are in puddled steel.

We need dwell no further on this mode of construction; less simple than that in which the ordinary stock-rail alone is used, and no better.

290. If confined to the switches there may be some reason for a special form; but it should be one which, while ensuring considerable horizontal stiffness to the switch, causes little if any cutting away of the counter-switch.

The points of Mr Van der Elst, of Braine-le-Comte (Pl. XXIV, figs 1 to 16) present a complete example of this arrangement. The counter-switch rail is left intact; while the switch, a rectangular bar in Bessemer steel, is cut away from the point where it meets the rail, only in its upper portion (figs 11 to 16).

(*) Instruction, dated May 20th 1861.

So that the tapered portion still retains considerable horizontal rigidity; especially useful when, the points being taken as "trailing" ones, the loaded switch has to slide obedient to the impulse, transmitted by the cross-ties, of its fellow switch.

The sliding-chairs have no cheeks to them; the stock rail being kept in place, on the outside by the spike, and on the inside by the edge of the bedplate, raised above it (fig. 5). In the point chair (and in the two next to it, which are similar), as the surface of the bedplate ought to project over the foot of the stock-rail, in order that the switch may be guided up to its contact with the rail, this extra height of bed is obtained by means of a wrought plate *p* (figs 3 and 4), rivetted to the cast one and brought over the foot of the rail. At the heel, a special chair *c'* (figs 7 and 8) receives the switch in a chamber and clear of the rail; on one side it is clipped by a wrought fishplate, while the chair itself acts as the fishplate on the other side. Two bolts connect the whole with these points the switch cannot, as with the ordinary forms, be retained within the sliding-chairs, as the rail is not fixed to any jaws by horizontal bolts : these last are however carried by the switch itself, and their projecting ends formed into studs *h*, *h*, *h* (fig. 1), which rest against the web of the rail. As this cannot turn over without carrying the chair with it, no inconvenience arises from the jaws being dispensed with.

The details of these points, recently applied in Belgium on the line from Lierre to Thurnout, have been carefully worked out; except in one point, that of the hollowed bed-plate, which it would not be wise to imitate.

On some lines there is a tendency to increase the breadth, and consequently the horizontal stiffness, of the switch. On the Southern of Austria, for example, in form it is like an ordinary switch, but laid on its side.

291. Though M. Hartwich (276) has been able to retain the stock rail for crossings, where all is fixed, yet with switches he has not been able to do so. With the latter he has been obliged to make use of bars of special form, less in height than the rail, if only to reduce their weight. In form they nearly resemble a Bridge-rail, solid however, and with a height of $3\frac{1}{2}''$ at the heel : they slide on cross ties fixed to the foot and to the web of the rails, affording a firm base to the switches, while at the same time they compensate the difference in the heights.

292. The stretcher-bars are sometimes placed too high, so as to be caught by the flanges of tire-worn wheels : as is often the case with the old form of points on the Eastern of France.

An useful precaution may here be named, employed on several railways, the Lyons system for instance, for the protection of pedestrians on the line; it consists in placing over the stretcher-bars a wrought iron hood c, c (fig. 40).

293. As the points of the switches ought not to coincide with the joints of the stock-rails, the portion of the counter-switch rails of the deviated ways, between the switch-point and the joint, is necessarily bent according to the angle of deviation. These bars are however delivered unbent at the yards, and are bent on the ground to suit the direction of the deviation. Three-throw points alone, which are almost always symmetrical, have the counter-switch rails bent before delivery.

The play of the line and also the cant (199-200) are dispensed with in the curves connecting the points and the crossings, each of which ought to be on a perfectly straight line. Thus when a change of way occurs on a curve, the setting out must be slightly altered so as to introduce two straights of sufficient length, one for the points, the other for the crossing.

§ XVII. — Laying of points and of crossings.

294. The laying of points and crossings and of through-crossings generally requires sleepers of special dimensions; as at their approaches the lines of rails rest on sleepers which are common to the intersecting ways. Thus with single points these sleepers are as much as 12′0″ long (Pl. XIX, fig. 3; Pl. XX, figs 1, 5 and 7); and with three-throw ones even up to 15′9″ in length (fig. 3).

The apparatus themselves are fixed upon cross sleepers, squared and with upright faces; which are tied together by longitudinals, the arrangement of which varies.

It may be advisable here to enter into some details on this matter; of a certain importance in itself, and also on account of the expense it entails. Three conditions must be fulfilled; a sufficient bearing surface on the ballast, a complete connection between the parts, and facility afforded in packing.

1° *Through-crossings.*— On the Northern of France the framework is formed with cross sleepers of but slight length, only 7′ 2″, × 8″ × 3″; connected by four large longitudinals, 12″, placed in pairs below the cross sleepers under the parts of the crossing (Pl. XIX, figs 3 to 9). The same arrangement exists on the Austrian State Ry, except that the scantling is rather heavier. On the Eastern of France the breadth of the bearing surface on the ballast is much greater, the cross sleepers being 10′·0″ long, and varying in width from 8″ to 12″ : three longitudinals, placed underneath, tie the cross sleepers together in the middle and near the ends (Pl. XIX, figs 10 and 11).

A right-angled through-crossing rests, naturally, on a sort of gridiron. On the Eastern of France this is formed (fig. 17) of seven pieces, 8'·8" long × 10'×6" : three being for the support of the principal way, its rails being continuous; while the four others connect the former ones, and support the interrupted and elevated rails of the secondary way.

2° *Crossings.* — On the Northern of France, the frame of the single crossing of 5°·30' is composed (Pl. XX, figs 7 and 8) of cross sleepers, from 10'·10" to 12'·2" long; with longitudinals below, 14"×3" under the outside rails, and 20" under the inside ones and the point-piece. In the double crossing (fig. 3) the cross pieces are 17'·0" long; and there are four rows of longitudinals below, two under the rails and two under the point-pieces.

On the Eastern of France the longitudinals are above, as with the through-crossing; two for the single crossing (Pl. XXIII, figs 1 and 3), and three for the double one.

On the central portion of the Orleans Ry, with the inverted ⊤ rail, the iron fastenings are depended upon to form the complete connection of the system; the longitudinals being done away with, excepting two short pieces which connect to the cross sleepers a small block placed under the middle of the point-piece. The cross sleepers, 12"×6", vary from 12'·6" to 14'·9" in length.

3° *Points.* — The same differences naturally recur here : longitudinals, below (Northern of France, Pl. XX, figs 1, 3, 5, 7 and 8), above (Eastern, Pl. XXI, figs 1, 2, 9 and 10), or dispensed with (Orleans, central section). The longitudinals, when below, may be placed in two ways; either underneath the rails as on the Northern of France, or clear of them as on the Lyons line.

The working-lever frame is placed on short longitudinals bolted to two of the cross sleepers, lengthened for this purpose to 14'·9" (Pl. XXI, figs 1, 2 and 9, 10); this arrangement is of course altered, when through of space the lever is made to work parallel to the line.

Longitudinals placed above the cross sleepers seem preferable to those underneath. With the latter, especially if of considerable breadth as on the Northern of France, the bearing surface on the ballast is increased, but with the former the whole of the surface is on one level, and consequently the framework rests on a layer of ballast of uniform thickness, while they also render packing more easy. On this head it may be noted, that the condition of ballast of a good quality, every where so important, is under these apparatus particularly indispensable.

" It is not sufficient ", says very rightly Mr Ledru (*), " for the proper working of

(*) Instruction, dated May 20th 1867.

" points and of through-crossings, that they should be solidly constructed and be well
" fixed. They must also find on the ballast a firm bed and one easily maintained.
" This can only be obtained with a clean and highly resisting ballast; fine sand will
" not do at all. When therefore the ballast in use on the running line is deficient in
" these qualities, some special ballast must be sought for the points and crossings
" and for the through-crossings, of the best possible quality."

To lay down these apparatus together with their approaches, under the conditions which have just been stated summarily, is both costly and restrictive : costly on account of the large dimensions of the timbers amounting to 2s/3 per foot cube; restrictive by the necessity imposed to store in due time the numerous parts which compose these framings.

The cube of special timber amounts, in the apparatus in actual use on the Eastern of France, to the following figures.

1° *Single symmetrical Point and Crossing* (*Radius of connecting curve* 656 *yards.*)

	Cube feet.
Framework for the Points	54
d° for the Crossing.	50
14 Special sleepers of 6 different types with length up to 11'.10".	65 $\frac{1}{8}$
Total. . . . . cube feet	169 $\frac{1}{8}$ = 6 $\frac{1}{4}$ cube yards about.

2° *Three-throw points and crossings* (*always symmetrical*).

	Cube feet.
Framework for the Points.	57 $\frac{1}{4}$
d° for the centre crossing of 7°.30'.	53
d° for the end crossings of 5°.30'.	70 $\frac{1}{2}$
16 Special sleepers, of 10 different types with lengths from 10'.4" to 16'.9".	86 $\frac{1}{2}$
Total. . . . . cube feet	267 $\frac{1}{4}$ = 10 cube yards nearly.

295. An investigation was made by the Permanent way staff of the Eastern of France into these apparatus, in order to render them simpler and cheaper, and it further included their wooden framework ; the result being to suppress entirely all special timber, excepting two longitudinals, *l*, *l*, in the single crossing (Pl. XXII, figs 33 and 34), and four in the double one (fig. 35). The cross pieces, varying both in length and in scantling, were replaced both in these apparatus and in their approaches by ordinary cross sleepers, set apart fort this purpose at the time of their reception as being the most regular; these picked cross sleepers were divided, as with the others, into joint and intermediate ones.

Figures 30, 31 and 32 of Plate XXII represent respectively the general arrangement of through-crossing, and of points and crossings. The details

of single crossings of 5° 30′ and of 7° 30′, and of double crossings are shown in figures 33, 34 and 35. The longitudinals, useless with the long cross pieces ordinarily employed, and very properly dispensed with on the Central Section of the Orleans line, are on the contrary indispensable with the new type of crossing of the Eastern of France (Pl. XXII, fig. 28); where however the iron fastenings of the running line are not sufficient, owing to the very great breadth of these apparatus, to form the connection between short cross sleepers merely framed into one another.

Each of the lines of way in the approaches to the through-crossing (fig. 30), has its sleepers notched for itself only; those of the one line leaving merely a free passage for the rails of the other. With points only, and for a few yards from the heel of the switch, can the cross sleepers be made common to the ramifications of both ways, and be notched for two or even three rails. Thus sleepers 1 to 5 (fig. 31) are the only ones thus affected in the single symmetrical crossing; and those marked 1 to 3 in the triple crossing (fig. 32). The condition evidently being, not to make a sleeper common to both lines, if doing so would entail its being notched too near to its extremity.

The success, rendered every day more probable, of an entirely metallic permanent way (184 and fol^ng), will certainly lead to an attempt, already made by Mr Hartwich (291), to suppress all timber in these special apparatus. As a first step however, by doing away with timber which is costly in dimension and in work, the Eastern of France have made a considerable advance; and one worthy to be noted and to be imitated.

CHAPTER X.

TURN-TABLES AND TRAVERSERS FOR CARRIAGE SHEDS AND FOR THE OPEN LINE.

Some mention of these appliances naturally follows after points and crossings, owing to the similarity, of their duties.

§ I. — Turn-tables.

296. The turn-table establishes a direct communication between those lines the axes of which are directed towards its centre. It consists essentially of a piece of line (in length equal, at least, to the wheel-base of the vehicles to be turned) moveable round a vertical axis passing through the point of intersection of the axes of the lines, and thus capable of being turned so as to form a continuation to each of them. The turn-table is, then, used for transferring single vehicles from one line to another, either by manual power or by that of horses; while points and crossings are employed for shunting trains drawn by engines, or even engines alone, the inconvenience of the much greater distances to traversed in the latter case being then very slight.

Turn-tables, much used in terminal stations in France and in England, have in Germany for a long period been only reluctantly accepted. Latterly, however, German engineers have somewhat overcome this prejudice, and have become convinced that turn-tables are indispensable for manœuvring with economy and rapidity. On the other hand, it has been admitted that in France this means of communication has sometimes been abused, both in passenger stations where turn-tables have been laid down on the main lines, and also in goods stations where access has only been afforded by their means to the lines alongside of the loading and discharging platforms.

Now adays, turn-tables are excluded from main lines in stations, run through without stoppage and almost always at a considerable speed. Turn-tables so placed are rapidly destroyed, and when badly laid they might be the cause of serious accidents.

Even in principal stations, where trains stop, turn-tables laid down on the main lines are soon worn out, notwitstanding the reduced speed of the trains

passing over them, and very often, with the brakes screwed down, the tenders especially, and the wheels locked.

The suppression of turn-tables on the main line generally leads also to their suppression on service lines; the principal duty of these turn-tables being to establish between parallel lines a communication, which might also be obtained by means of a traverser (313); an apparatus less simple in working than the turn-table, and requiring on the part of the men engaged in shunting somewhat more attention and care, but which leaves fixed and unbroken the parallel lines to be placed in communication.

A traverser was substituted, in 1865, at the important station of Nancy, on the Eastern of France, where the maintenance and renewal of turn-tables entailed considerable expense, on account of the large number of trains and engines shunting about that passed over them. As shown by fig. 8, Pl. XXXI, by means of two traversers thirteen out of seventeen turn-tables were suppressed, those bearing the numbers 2, 4, 7 and 16 being alone retained for certain waggons that required turning.

At Belfort, one of the junctions of the Eastern of France and of the Lyons line, a traverser placed in 1866, allowed four turn-tables to be dispensed with out of seven, 14 ft. 9 ins in diameter, which afforded communication between the up and down lines, and gave access to the carriage sheds. The remaining three were only retained, as at Nancy, for turning a few guards' vans with projecting hoods to be included in the trains made up at Belfort. The stations of Luneville and Mourmelon present other examples of these modifications; about which it would be useless to dwell further, though it was advisable to point them out.

297. In the case of locomotives, as well as, of the special carriages just named, turn-tables fulfil an essential duty. As engines are not, like most carriages, similar at both ends, they must as a rule be turned end for end at the extreme points of their run. With tank engines in certain cases this necessity may be obviated; but with other classes of locomotive the practice of running tender forward, though of frequent occurrence in England, is only permitted in France in the case of slow trains and with short runs. It is especially in suburban lines, the traffic of which is very great at certain periods of the year, that this practice is useful, not merely because it dispenses with the necessity of laying down engine turn-tables, but also because it saves time. These exceptions, however, are not of frequent occurrence; and all engine depots should be provided with a turn-table.

It is manifest, that the engine may also be turned end for end by means

of a double spur line as shown at fig. 23 (Pl. XXVII); but this method would not be economical as a general rule, on account of the necessarily large radius of the curves, nor convenient in working.

298. In order to avoid the necessity of turning the engine and tender separately, and especially with a view to dispense with the large number of men which this operation, performed in that case by hand labour, would necessitate, turn-tables at depots are now almost always constructed of such a diameter as will permit of engine and tender being turned together. Besides, this arrangement was a necessity with a type of locomotive, the Engerth one, much in use some years ago but now abandoned; in which engine and tender are so closely connected that it took a long time to disconnect them, and only to be effected in the workshops when repairs are required.

These large turn-tables also serve, with circular engine sheds, to afford communication between the station lines and those of the sheds, which converge towards the centre of the turn-table.

For a long time this circular arrangement was used only in France and in England, while in Germany preference was given to rectangular sheds, with lines of way parallel to each other, reached by a traverser working on rails, laid at right angles in the traverser pit (310). In France, objections are made to the latter arrangement, on the one hand because a turn-table is always necessary to turn the engine, and on the other on account of the long time occupied in working the traverser with hand winches, and with a long distance to traverse. At the present day, the addition of a portable engine to work the traverser, thus rendering the operation less costly and much more prompt, has considerably lessened the gravity of the objection, so that rectangular running sheds are increasing, and in large goods stations the two systems are often seen together.

Large turn-tables, as well as traversers, are also fitted with portable engines, when the traffic is sufficiently great to justify the outlay.

299. 1st. *Turn-tables for carriages, or for tank engines.* — A detailed description of the various types of turn-tables would occupy a space more justly claimed by subjects of greater interest, either of themselves, or on account of their influence on the safe working of the line. A few examples will suffice.

Turn-tables for carriages and for tank-engines on the one hand, and those for engines and tenders combined, on the other, form two distinct categories,

not only on account of their relative sizes, but also by the mode of construction adopted.

The diameter of turn-tables depends, it is evident, on the length of wheel-base of the vehicles to be turned — a dimension smallest in goods wagons, larger in passenger carriages, and larger still in some engines. The diameter of turn-tables at the present day is generally 11 ft. 6 ins for the first, 14 ft. 9 ins for the second, and 16 ft. 6 ins on the Paris and Marseilles line. A diameter of 17 ft. suffices for the generality of locomotives, even those with the trailing axle behind the fire-box. In designing the fixed plant of the Paris and Strasburg line, it was thought prudent, so as not to restrict the future dimensions, to increase this diameter to 19 ft. 8 in., a dimension which has been applied successively to the whole of the Eastern system; but this is larger than necessary, even for the Crampton engines, the wheel-base of which is 14 ft. 9 in. It is, besides, evident that turn-tables of a diameter too small for engines should be constructed and laid down as substantially as larger ones, when they are placed on lines run over by engines.

A turn-table consists of three parts : 1st, the moveable platform; 2nd, the fixed base, and the wall of the pit, or curb; and 3rd, the intermediate supports consisting of a ring of rollers and a central pin or pivot.

The moveable platform is generally formed of cast iron; sometimes mixed, of cast, or wrought iron and timber; and frequently of plate iron.

The fixed base, and the curb are of cast-iron, and sometimes of timber, though very rarely so now.

The principal duty of the central pivot is to preserve the position of the turn-table, which the concussions from the wheels tend to displace, and to equalize the pressure brought to bear near the circumference in order to cause it to revolve. Only a small portion of the load ought however to be borne by it, which should be carried by the rollers.

Men working the turn-tables are apt, however, to load the pivot, so as to diminish the resistance; but, in that case, shocks are communicated from the platform to the rollers each time a carriage is run on or off. These men are forbidden to alter the distribution of load; the most certain means, however, to prevent any tampering is to secure by a pad-lock the cap, which covers the centre of the platform and the nuts of the bolts which attach it to the pivot; this cap also prevents dust from reaching the pivot.

The rollers, of hard cast iron, may be arranged in three ways : 1st, as forming part of the platform; 2nd, as forming part of the base; and 3rd, as independent of both. Figs 1 to 5 of Plate XXVI show an arrangement in which the two first arrangements are combined. The third method, in which the

rollers, loaded on the top, only introduce a friction of rotation, is by far the most generally employed, and is indeed greatly preferable to the two others, in which the rollers sustain the load on their axles. The independent rollers are centered by means of rods which fit into a collar round the pivot. They are generally vertical. The roller paths, of circular rails, one of which is attached to the moveable platform, and the other to the fixed base, must therefore be conical, as are the rollers also. In that case, the slight horizontal displacement, due to the greater or less amount of play of the pivot in its socket, cannot be communicated to the platform by the action of the wheels without, at the same time, throwing it to some extent out of level, thereby increasing the effect of the concussions.

This difficulty may be avoided by inclining the rollers at an angle with the vertical equal to their conicity. In that case the platform rests on the horizontal portions of the rollers by means of a rail which in this case must be horizontal; and a slight shifting of the platform no longer causes it to be thrown out of level. It is clear, that the ends of the horizontal rods which keep the rollers in place must in this case be bent at right angles to their base.

This arrangement of rollers has been imitated in two very important works executed at Creuzot : the double-armed swing bridge over the Missiessy at Toulon, and the large double swing-brige over the Penfeld at Brest, the design of which is due to Mr Oudry.

300. *Cast-iron turn-tables.* — The platform, almost always carrying two lines of way laid across each other at right angles in order to form a connection between two lines perpendicular to each other, is formed : 1st of four girders PP (fig. 16, Pl. XXV), crossing each other in pairs corresponding to the four rails; 2nd, of four radial webs R, R, which connect them to the socket of the pivot, to the collar of which the floor is united by four bolts with the nuts uppermost; and 3rd, of an outside rim. It is but seldom now even with tables of small diameter, that the platform is cast in a single piece; by dividing it into several parts, the tendency to unequal contraction is lessened, and therefore also the danger of fracture.

In the 11 ft. 6 ins turn-table of the Eastern of France (Pl. XXV, figs 15 to 32) the rim forms one piece, and the inside portion another; the ends of the girders are bolted into steps cast on the rim (figs 19 and 20). It is also to avoid fractures, often resulting from the concentration of metal at certain points, that the arrangement where the radial pieces join at the middle of the girders, is preferred to that in which they come in at the points of intersection, *o*, *o*, (fig. 16). The rails of bridge section, are laid over the girders

to which they are bolted (figs 15 and 23) with oak packings *f*, *f*, laid between, to deaden the concussions.

The base, comprising the socket of the pivot, six radial bars, *r*, *r*, *r*, a roller path *c*, in form of a conical rail, and an outside circular flange *a*, to connect with the curb (figs 15, 16, 21, 22, 26 and 30), is better adapted by its form to be cast in a single piece.

The curb, cast in six segments, *d*, *d*, *d*, has eight recesses forming chairs, in which are bolted the ends of the fixed rails, and four wrought iron stop-boxes to take the stops (figs 15, 16, 26, 27, 28, 30, 31 and 32); there are six rollers *g*, *g*.

In the 14 ft. 9 ins turn-table of the same system, the girders and the radial pieces are cast in one piece, but the rim is in four parts and the curb in eight. The principal difference consists in the method of forming the base, which is of timber. To this framing is bolted a cast-block for the pivot-socket; also a roller-path, likewise of cast-iron, turned on its upper face, formed of four segments united together and provided with lugs to receive the bolts which fasten them to the frame. The number of rollers is increased to ten.

The 14 ft. 6 ins turn-table of the Orleans line has the bottom frame of cast iron, as is the platform; they are each in two parts, united by means of wrought iron-plates bolted on.

On the Mediterranean system, the 14 ft. 9 ins and 16 ft. 6 ins turn-tables have a platform of cast and wrought iron combined (Pl. XXVI, figs 7 to 35).

A central casting comprising the radial pieces, B, B, B, B, and the interior portions, *p*, *p*, of one of the sets of wrought iron beams is fixed by the bolts, *b*, *b*, on the one hand to two longitudinals, *l*, *l*, forming the second set, and on the other, by means of angle irons, *c*, *c*, to four outside beams *l'*, *l*,' *l'*, completing the first set. The eight ends of the beams are themselves bolted to the lugs, *o*, *o*, *o*, cast on the outside rim, also cast in two parts and bolted together. The upper portion of the beams (excepting the two cast-portions, *p*, *p*, of double T section) has angle irons, *k*, *k* (fig. 7) fitted to it, affording a sufficiently wide base to rivet the flanges of the bridge rail.

This platform is fixed upon a cast frame with eight arms; cast in two parts, each a semicircle.

WEIGHT :

14 ft. 6 ins *Turn-tables.*	Tons. cwt.	16 ft. 6 ins *Turn-tables.*	Tons. cwt.
Moveable Platform	5 . $3\frac{1}{4}$	Moveable platform	6 . $4\frac{1}{2}$
Fixed portion and rollers	4 . 15	Fixed portion and rollers	6 . $2\frac{1}{4}$
	9 . $18\frac{1}{4}$		12 . $7\frac{1}{4}$
These weights are thus divided :	Tons. cwt.	These weights are thus divided :	Tons. cwt.
Wrought iron	2 . 2	Wrought iron	2 . $12\frac{1}{4}$
Cast iron	7 . 6	Cast iron	9 . $2\frac{3}{4}$
Steel	0 . $10\frac{1}{4}$	Steel	0 . $12\frac{1}{4}$
Gunmetal (2 lbs)		Gunmetal (2 lbs)	
	9 . $18\frac{1}{4}$		12 . $7\frac{1}{4}$

On the Orleans line, a solid bridge rail, is bolted direct to the cast girders; which is preferable to the rivets in use on the Mediterranean line (Pl. XXVI, fig. 6).

In the 19 ft. 8 ins. engine turn-table of the Eastern of France (Pl. XXVI, figs 36 and 37) the platform, beams, and rim, are cast in two parts; the radial arms, R, R, R, cast separately, are bolted to faced bearings, *m*, *m*, at the intersections of the beams; these intersections are lightened out, to avoid a too great quantity of metal in one spot. The pivot and the roller-path, which latter forms a support for the curb, are erected on a wooden frame, ρ, ρ, ρ, the parts of which are united by bolts.

301. *Turn-tables with platform of iron and wood.* — Figs 1 to 14 (Pl. XXV) represent two turn-tables of the Austrian State Ry with rollers hung from the platform and for waggons with small wheel-base. The diameter of one of them (figs 8 to 14) is 9 ft. 2 ins, and that of the other (figs 1 to 7) only 6 ft. 6 ins. The beams are formed in the latter of a single rail, and in the former of two Vignoles rails, riveted together base to base (figs 13 to 14). Four bars, *p*, *p*, bolted to the sides of the beams unite them to the pivot. The base is formed of a square wooden frame with two diagonals to it, supporting the pivot and the roller-path of the rollers, *r*, *r*, four only in number. Two different kinds of timber wheel frames, one above the other (figs 6 and 7, and 11 and 12) form the curb.

On the Northern of France in the 13 ft. 9 ins turn-tables, the platforms are composed of cast-iron and timber (Pl. XXV, figs 33 to 44). Four arms BB, of double T section, cast in one, are connected at their ends, by means of bolts and of keys, *k*, *k*, to a rim formed in two parts joined together by

six-bolted fish-plates. The beams are of timber; in one of the sets, each beam P (figs 33 to 35), is in two parts, supported at one end by the cast-iron arm, B, at right angles to it, and at the other end by a seat on the rim to which the piece is bolted; in the other set, each beam, P′, interrupted where it meets those of the first set, is formed of four pieces; those outside are supported by the rim and by shoes bolted to the sides of the beams at right angles; and the intermediate ones by the latter and by the cast arms. The timbers carry an ordinary Vignoles rail.

The base has nothing special to it; it consists of an eight-armed framework, cast in two pieces with its roller-path.

302. *Plate iron turn-tables.* — These have been adopted on several lines, among others the Northern and the Eastern of France. The beams, the four arms which connect the platform to the pivot socket by means of gusset pieces, and the rim, are of double T iron, strengthened by plates rivetted on. The roller-path consists of a conical ring, held by rivets with the lower head countersunk. Wrought plates, above and below the framework and tying it together, render the platforms firm, though hollow, yet rigid. The result, however, has generally been but poor; the platforms get out of level and the rivets start. These defects may be partly set down to a fault in design; insufficient scantling of the parts. On account however of the necessarily small size of the boiler plate platform, which receives the concussions of the wheels direct, rivets should manifestly be excluded as being too subject to work loose under the influence of the shocks to which the apparatus is liable. With turn-tables one condition is of primary importance, that of a sufficient mass of material; and no ingenuity of construction can dispense with it.

303. With cast steel itself, notwithstanding that it is greatly superior in toughness to cast iron, the scantling can only be reduced with great caution. Difficulties in casting, on account of the high temperature of the molten metal, and of the great number of air-holes, have, up to the present time, been obstacles to the employment of steel for this purpose. The arrangement, already mentioned (299) with two sets of rollers, was designed by Mr Poulet with a view to make use of cast steel; but the experimental ones made by Messrs Petin et Gaudet were so honeycombed, that there the matter ended.

Mr Poulet has, however, since erected at the Paris terminus of the Northern Railway a 14 ft. 9 ins turn-table with the frame of the platform of cast steel; the rim is of wrought iron, and the fixed base, eight-armed, is of cast-iron. The remarkable part of this apparatus is the mode of fixing employed: 1st, when

at rest, the platform bears upon a ring of supports capable of being regulated by a common motion and similar to the system of wedges in use with some swing bridges; 2nd, when at work, the supports sink, and the load is concentrated on the pivot, thus rendering the motion easier. This is provided, be it understood, that the centre of gravity of the whole lies within the axis of the pivot. Concussions are thus avoided, while the labour of working is reduced.

The wedging is accomplished by eight large screws, worked together by means of eight short chains connected by rods, and each of which actuates a toothed sector attached to the screw. The load is transmitted to the pivot by means of five cast steel washers having a convexity of $\frac{1}{8}$ of an inch, and forming a spring.

The principle of this apparatus, applied with success, as will be seen farther on (308), to large turn-tables with a single line of way for engine and tender, is judicious; but in the example just given the execution of the work left much to be desired : frequency of running off the line, and difficulty of maintenance have prevented the system from becoming general.

304. As turn-tables, even those of the smallest dimensions, have almost always a diameter considerably larger than the gauge of the line multiplied by $\sqrt{2}$, the rails of the two lines at right angles intersect each other on the turn-table itself, which must, on that account, present the arrangement pointed out (255) for right-angled through crossings: that is to say, that the rails of the two lines of way are interrupted, if the turn-table does not form part of a main line, one of them have its rails continuous, and the other its rails severed and at a higher level. On account of the very small diameter of the turn-table (301) represented by figs 1 to 7, Pl. XXV, the points of intersection are outside the turn-table, and are fixed.

The lines which abut on the turn-tables being generally at the same level, the superelevation must be obtained, in the approaches to the turn-tables, by gradients.

305. *Foundations of turn-tables.* — For a long time past, turn-tables have been laid down on regular foundations of masonry. This caused, especially on embankments, a considerable expense for an insignificant result. Masonry foundations are not more requisite for ordinary turn-tables than for points and crossings; like the latter they should be laid on the ballast. In embankments, it is advisable to lay down at the bottom of the excavation a layer of broken stone on which should be a tolerably thick layer of good gravel ballast, well punned.

On sidings not run over by engines the bed-plate is always laid on the gravel direct; but in the case of lines over which engines run it is often specified, that the bed-plate be laid on a timber framework, in order to distribute the weight over a large surface of ballast. This course however would appear not to be necessary if the bottom is tolerably solid. The turn-tables run over by engines are often, in fact, laid down like the others, and no harm results therefrom.

306. 2nd *Large turn-tables for engines and tender.* — The large diameter and great weight of these turn-tables, the large sectional area of their long beams which have heavy loads to carry, the impossibility of laying them down at slight cost, like the preceding, on a cast-iron bed-plate forming the usual base of the system, and the necessity of preventing any buckling, or settling, demand considerable modifications both in the construction of the appliances themselves, and also in their foundations. In this double respect, large turn-tables more nearly resemble large machines in workshops than ordinary adjuncts to the permanent way.

These large turn-tables have seldom more than one line of way. The platform is, therefore, practically a bridge; it is generally preferred, for the sake of convenience, to cover in the whole of the pit, but the supports to the segments outside the line of way are constructed much less solidly than the bridge itself, although they overhang, or are only supported each by a special roller.

The complete circle of rollers of ordinary turn-tables does not, in fact, exist in these large specimens; or, if it exists, it has only a considerably reduced diameter, and its duty is to give to the large beams of the bridge intermediate points of support between the large outside rollers and the pivot, which sustains a considerable portion of the load. The outside rollers are no longer independent, but form part of the turn-table, they are loaded on their axles, and instead of being distributed over the whole circumference, they are applied only to the portion which works, that is to say to the bridge. For large diameters, usually comprised between 36 and 40 feet, iron longitudinals are generally employed. The recommendations of the Dresden meeting advise the use of wrought iron and steel for these parts (*).

On the Northern of France Railway, for turn-tables of 39 ft. 6 ins diameter, instead of the inner circle of rollers, an ordinary 13 ft. 3 ins turn-table has

(*) Vereinbarungen, etc..... Bahnhofs-Anlagen, art. 69.

been used, the platform of which carries the heavy longitudinals bolted on it. The girders are of plate iron; the roller-path of the large rollers is 33 ft. 6 ins in diameter.

On the Eastern of France Railway (Pl. XXVIII, figs 1 to 4) the beams, P, are of oak, cut square, 38 ft. long, and 1 ft. 8 ins square. They are borne at the ends by a pair of plate bearers, E, E, hung from the axles of the rollers, G, G; between these rollers and the pivot they are supported by a cast-iron ring, *c*, *c*, *c*, 12 ft. 8 ins in diameter, bearing on a live-ring of eight independent rollers, *g*, *g*, *g*, the centre of which receives the pivot.

" The working of these turn-tables, " says Mr Vuillemin, engineer-in-chief of the Permanent Way (*), " although on the whole tolerably satisfactory, is nevertheless " defective owing to the want of rigidity in the timber longitudinals. Whether these " parts become warped or impaired in time, or whether their sectional area is not " sufficiently large, and that they deflect under the load they have to sustain, it is " generally found that the bearing rollers are much too heavily loaded. The cast- " iron roller-path and the rollers soon become damaged, and the rolling motion does " not work properly. Hence the maintenance of these parts in an efficient state " becomes costly. Timber longitudinals of the sectional area above given are very " difficult to meet with on account of their length. And, besides its being almost " impossible to obtain balks of a greater scantling, it is doubtful whether, even in " that case, their rigidity would be sufficient."

The consequence was that the company determined to replace the wood beams by plate girders, at the same time making use of the other parts of the turn-table (Pl. XXVIII, figs 5 to 8). At the same time the central portion was strengthened, and the diameter of the larger roller-path, R, was reduced, which allowed the inner ring, *c*, *c*, to be dispensed with, and the load on the pivot to be considerable increased; the diameter of the latter was changed from 5 to $6\frac{1}{4}$ inches, the area of the cast-cross tie being increased in proportion. Besides the four large cast-iron rollers, G, G, carrying the girders, two others, G′, G′, in conjunction with the latter, carry the planking of the segments outside the line of way, and the timber framing, ρ, ρ, ρ, on which it is laid. This alteration, made to the turn-table at Châlons-sur-Marne, gives good results.

The boiler plate turn-table, 37 ft. 6 ins in diameter, of the Austrian State Railway has an arrangement similar to the preceding (Pl. XXVII, figs 1 to 18). A fixed pivot, ϖ, four principal rollers, G, G, and two small lateral rollers, *g*, *g*, carry the whole system. The cross-stays which bear on the large rollers

(*) Manuscript note of 16th July, 1867.

are of plate iron, as are also the girders. The rails are rivetted direct to the latter (fig. 14), a practice not found to be inconvenient, as the engines do not run at a great speed over these large turn-tables, which are besides much more massive than the ordinary turn-tables laid down on the open line.

Figs 1 to 5 of Plate XXIX represent the turn-table of the new engine shed of the Berlin terminus of the Potsdam and Magdeburg Railway. It is a simple bridge formed of two plate girders, 2 ft. 3 ins deep in the middle, carried only by the pivot and by four large rollers, *r*, *r*, two bolts *v*, *v*, worked together by means of the lever, *l*, and the rods, *t*, *t*, *t*, serve to make the axis of the table coincide with the prolongation of that of each pair of rails which it serves.

307. *Working of large turn-tables.* — In Germany, turn-tables of 33 feet in diameter, laid down outside engine sheds, are often worked by means of long hand-spikes inserted in inclined sockets bolted to the turn-table. This method is insufficient for large diameters and heavy engines; it also necessitates the leaving of a clear road outside the turn-table, which is not always possible.

The method most generally adopted is to give, by means of geared winches worked either by hand or by a portable engine, a rotary motion to one or two large rollers which partially carry the load, their adhesion causing the rotation of the whole system. The Berlin turn-table is arranged in this manner (Pl. XXIX, fig. 2), *m* being the handle of the winch.

Objections are sometimes made to this method, that it is defective through an insufficiency of the load on the actuating rollers, in consequence, either of a very unequal distribution thereof, or of a settling of the foundations. These objections may be well founded when the motor is a portable engine acting only on one roller; but they are of less force in the case of many turn-tables worked by hand and provided with a couple of winches actuating two rollers diametrically opposite to one another; if one of them does not receive its proper load, the other takes a greater load and thus the equilibrium is maintained.

The turn-tables of the Eastern Railway of France are provided, either with a single winch actuating a system of wheels and pinions gearing into the roller-path of the large rollers, formed of segments toothed on their inner face (Pl. XVIII, figs 1, 2 and 3); or with two winches acting on two of the four principal rollers, diagonally opposite. In the altered turn-table at Châlons-sur-Marne (303) one of these winches has been dispensed with, and the portable engine, of two Horse-Power, acts on a single roller, the adhesion of which is perfectly sufficient. This may, indeed, be easily imagined, for even when the concentration of a larger portion of the load on the pivot might

reduce the pressure on the actuating roller, notwithstanding the suppression of the inner circle of rollers, it also reduces the power necessary to work.

In those turn-tables in which the winch works into a toothed ring, the latter, instead of being at the bottom of the pit, and in one piece with the roller-path as on the Eastern of France and the Lyons railways, is often fixed on the top of the curb.

308. *Turn-tables with the platform balanced on the pivot.*—A turn-table with a single pair of rails is in fact only a double-armed swing bridge; with the exception, however, of this circumstance unfavourable to the turn-table, that it is moved under its load, while the bridge is moved unloaded. This is, after all a question of strength of materials; and it is very natural to apply to the one the arrangements indispensable to the other, that is to say, the wedging, when at rest, by supports at the ends, which are lowered during rotation.

This arrangement has been adopted, for several years, in England, Belgium and Germany. In France it has hitherto only been introduced on the Northern Railway, but it will certainly become general. It is especially suitable at depots where the traffic is not sufficient to justify the erection of a portable engine; and where, for the same reason, the number of hands is not large. An arrangement which permits of two men rapidly turning a heavy engine is very suitable to these conditions.

The position, with respect to the axles, of the centre of gravity of an engine and tender united varies with the different types. It varies, also, in the same engine, with the quantity of water in the boiler, and the load in the tender. A certain latitude must, therefore, be given for the engine and tender to be brought into such a position as is suitable for working; that is to say, so that the centre of gravity of the moveable load be thrown on the pivot. These turn-tables ought then to have, for a given rolling stock, a larger diameter than others. For engines of the maximum wheel-base at present in use this diameter is 46 feet. Engine-drivers soon get accustomed to, and, almost at the first attempt, bring up their engines on the turn-tables in the desired position.

Figs 6 to 18 (Pl. XXIX) represent the balanced turn-table of the Northern of France Railway. The two plate girders, 3 feet deep in the middle and 2 feet at the ends, are united by horizontal plates and by a strong webbed casting, hung on the pivot, p, $5\frac{1}{2}$ inches in diameter. The bearing of the latter is on a wrought iron shaft, A, 9 inches in diameter.

The section of the girder is not symmetrical. In order to prevent deflec-

tion, the bottom plate, in compression, is wider and thicker than the top plate, in tension. The neutral axis is thus below the half-height, 12 inches from the outer fibres in compression.

At each end of the girders a locking bolt, *v*, is provided, similar to the two stop bolts fixed on the centre line of the Berlin turn-table, but having quite a different duty to perform : they support the whole system while the engine is running on or off the table. There is at each end a lever, *l*, which works the two bolts from the same side. The excess of breadth of the platform leaves a passage, *h*, *h*, free on each side; hand-rails, *g*, *g*, rendering movement thereon more easy.

The cast-iron rollers, *r*, 2 feet in diameter, are merely provided in case of need; they are, however of large size, in order to prevent fractures in the event of the bolting of the platform having been forgotten.

The play between the rollers and the roller-path when the girders are not loaded has been fixed at nearly $\frac{1}{4}$ inch; when the girders are loaded, this is reduced by the deflection and the compression of the pivot. Under the heaviest engines the deflection does not exceed $\frac{1}{16}$ of an inch; there remains, therefore $\frac{3}{16}$ of an inch to allow for a possible slight settlement of the foundations.

The heaviest engines on the Northern of France line (the Engerth type with five pairs of wheels) weigh, in running order, about 62 tons — nearly three tons more than the engines with four cylinders and six pairs of wheels — and in this state the centre of gravity is generally 13 ft. 6 ins from the leading axle, that is to say a little in front of the middle of the wheel-base, which is 28 ft. 6 ins.

The engine being run on in such a position, that the centre line of the pivot passes through the centre of gravity, and taking the moments relatively to the section, *m*, *m*, taken at 2 ft. 9 ins from the middle, and which has the greatest strain (the intermediate portion being considerably strengthened by the ribbed casting and the plate webs) the following load is arrived at for each of the girders :

	Foot-tons.
Sum of the moments of deflection due to the temporary load.	106.18
» » » » » » » » » permanent load.	50.37
	156.55

which develops in the outer fibres at *m* a strain of 3 tons $3\frac{3}{4}$ cwt. per square inch.

The pivot, sustaining 61 tons $14\frac{1}{2}$ cwt. + 21 tons 19 cwt. = 83 tons $13\frac{1}{2}$ cwt., and, having a sectional area of 26 square inches, is subjected to a strain of 3 tons $3\frac{1}{2}$ cwt. per square inch. The steel socket of the wrought iron shaft

bears a load of 5 tons $2\frac{1}{4}$ cwt. per square inch. The eight bolts attaching the ribbed casting to the pivot: 2 tons 17 cwt. per square inch.

The wedge bolts, v, v, are $3\frac{3}{8}$ inches high, and 3 inches wide; they are worked by means of a lever, the arms of which are in the proportion of 1 to 16.

If the bearing surface of the bolts were horizontal, the force exerted at the end of each lever to free the floor would be, $\frac{13^{\text{tons}}\,13\frac{1}{2}^{\text{cwt}}}{4} \times \frac{1}{16} \times 0{\cdot}1 = 2\frac{1}{2}$ cwt, taking 0·1 as the coefficient of friction. A slight taper given to the bolt reduces this strain. When the engine is accurately placed in the centre, and the platform released, two men can easily turn the whole by pushing the engine sideways.

In the United States, turn-tables are laid down almost on the same principle, although, the load is not brought exactly on to the pivot but on to a livering of conical steel rollers; and 2ndly there is no arrangement for clamping the platform; but its place is probably supplied by hand keys, the rollers being so much the less in a position to accomplish this duty as their clearance is considerable, according to Mr Kirchweger (*) as much as from $\frac{3}{4}$ to $1\frac{1}{4}$ inch. The girders, notwithstanding their length — about 49 feet — are of cast-iron, which is accounted for by the superior quality of the metal.

When the whole is in equilibrium, a single man can, by the aid of a lever, turn the heaviest engine.

Want of space, or the nature of the ground, may lead, in certain cases, to the pivot being placed near to one end, as in the case of swing bridges with a single span. Some examples of this arrangement are found in England and Germany. It has been adopted at the Stettin station, on the Stargard and Posen line, for affording communication between the carriage shed and the main lines (Pl. XXVIII, figs 9 and 10).

309. *Erection of large turn-tables.* — The foundations of these large turn-tables are always costly, even on good ground, if it were only on account of the dressed stone required by the fastenings; in bad ground, the cube of the masonry be very considerable. Figs 20 to 22 in Pl. XXVII represent the foundations of the turn-table in the Paris terminus of the Mediterranean line, laid in about $16\frac{1}{2}$ feet of embankment, and which had on that account to be carried down to the solid ground at that depth.

They consist of three circular walls and a central mass of rubble masonry

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(*) Notes taken during a trip to the United States. — *Organ für die fortschritte des Eisenbahnwesens*, of 1867.

with ashlar coping. The first wall carries the curb, the second the roller-path of the outer rollers, and the third that of the inner rollers. In the centre is the solid carrying the pivot and tied to the inside circular wall by four radial walls, forming this inside circle and its centre into a single mass.

This division of the supports and consequently of the foundations, also, is evidently not economical; since grouping them together reduces the cubic content of the masonry. Thus, by bringing the outer rollers near to the ends of the girders, and consequently their roller paths towards the curb, the foundations of the two get mixed up together, as the roller-path is laid down on one of the curb-footings.

The cube of the masonry is still further reduced when the girders are sufficiently strong to dispense with the intermediate rollers, as in the turn-table at the Leipsic station of the Saxo-Bavarian Railway; the lattice girders having sufficient rigidity to require support only at the ends and in the middle.

Large turn-tables are sometimes laid down with an uniform foundation-bed. On the Northern of France Railway, for instance, a bed of concrete 1 ft. 8 ins. thick (a dimension evidently varying with each case), is combined with a timber framing bolted together; replacing the ashlar for the fastening down stones, and distributing the pressure over the concrete, in which the framing is embedded.

Turn-tables with the load on the pivot are not, as far as the foundations are concerned, as economical as may at first be supposed; because the rollers, notwithstanding their secondary duty, always require a very strong roller-path, and, also since the pivot must rest on a mass of masonry much greater than that of ordinary turn-tables (Pl. XXIX, figs. 12 and 18).

§ II. — Carriage shed traversers, and traversers on the level.

310. 1st *Carriage shed traversers.* — The lines of way in carriage sheds terminate in a pit, on the bottom of which is laid a transverse pair of rails for the traverser to run upon. As it is considered desirable to combine a slight depth of pit with a tolerably large diameter for the traverser wheels, the platform carrying the pair of rails is hung from the axles.

Figs. 11 to 19, Pl. XXX, represent the traverser of the Lyons railway, for carriages which when loaded may weigh up to 20 tons. The frame is formed of two pairs, P,P, P_1P_1, of rolled iron girders of double T section, connected by two cross girders, L,L, laid directly under and in line with the

rails. Between the rolled girders run the wheels, having, therefore, double journals, the diameter of which may be reduced in consequence. The shank of the axle is, nevertheless, retained, but of a reduced section; its only duty being to ensure an even rotation of the wheels on both sides, and thus to counteract the tendency of the traverser to assume an oblique position.

This traverser weighs 3 tons · 13 ½ cwt., divided as follows :

	Tons.	Cwt.
Wrought iron	3 ·	3 ½
Cast iron		9
Gun-metal and other materials		1
	3	13 ½

The line of way laid at the bottom of the pit has a gauge of 13′ · 9 ½″. The bearing rails are of the Vignoles type, as are also the guard rails ; which are connected to the former every 3′ · 3″ by a cast-iron distance block, *k*, and a bolt, *b* (fig. 19). Both of them are fished, and are made to break joint so as to permit of this being done. It is only at the joints of the bearing rails that there are sleepers, *t*, *t*, properly so called, 16′.6″ long. The intermediate supports, θ, are pieces of short length, about 2′ · 9″. The double rail is spiked to its bearers with a cant of $\frac{1}{20}$, the wheels of the traverser being ordinary carriage wheels. At the end of the pit, the bearing rails are bent up, so as to form a stop for the traverser. The sides of the pit are lined with rubble masonry, with timber edging, 7×10 inches, to receive the ends of the carriage-shed rails.

The traverser of the Austrian State Railway (figs. 7 to 10) is 29 ft. long. The rails are carried by four pairs of rolled girders, P,P,P ; each pair is hung to the axles of two wheels. There are consequently eight wheels in all rolling on four Vignoles rails, V,V,V. Longitudinal plate beams, *l*,*l*, rivetted to the sides of the cross girders sustain the rails throughout their whole length. The traverser is worked by geared crab winches, actuating two wheels, R,R′, keyed on the same shaft; two stop bolts, *v*,*v*, fix the traverser exactly opposite the lines of way which it serves.

311. Traversers for engine and tender present no essential differences from the carriage traversers, except those due to the size and weight of the load. In the traverser of the Eastern of France Railway, the platform, 38 ft. long, is carried, as in the preceding example, by four pairs of girders, and by eight wheels. The shank of the axle is retained in one of the rows of four wheels, not only for the reason just mentioned (310), but also for the sake of utilizing the adhesion due to the load on these four wheels, to assist in working the traverser.

The weight of this traverser is :

	Tons.	Cwt.
Wrought iron.	16 ·	0
Cast iron.	3 ·	11 $\frac{3}{4}$
Gun-metal.	·	4 $\frac{1}{2}$
Oak (49 $\frac{1}{3}$ cube feet).	1 ·	7 $\frac{1}{4}$
Total.	21 ·	3 $\frac{1}{2}$

To this figure must be added the weight of the two winches, and generally at the present time, that of a portable engine also; that is to say about $21\frac{1}{2}$ cwt.

Sometimes bearing springs, not very flexible however, are fitted to these large traversers; they are always useful in distributing the load, over several points of support. The traversing action is generally caused by the rotation of one of the rows of rollers, and sometimes with the assistance of a rack and pinion.

312. Mr Ramsbottom, the late locomotive superintendent of the London and North Western Railway, designed an ingenious apparatus in which the traverser is replaced by platforms, each one of which serves three or four lines of way. These platforms are fixed, the rails which they carry being alone moveable and sliding transversely upon and below them. An exact idea will be conveyed of the apparatus, by supposing a kind of horizontal chain pump, the buckets of which are replaced by short lengths of pairs of rails, double the number of fixed lines of way to be served. In the case of ordinary carriages, the moveable rails are gripped at four points; there are, therefore, four chains, the articulated links of which are wound on two polygonal drums. One of them, worked by a winch imparts motion to the system of chains and rails, which slide over the platform and pass freely beneath it, the girders which carry them being supported only at each end. These girders correspond to the fixed rails of the permanent way, so that the moveable rails are brought directly over them when in such a position as to form a continuation of the fixed rails.

313. 2nd *Traversers on the level.* — The problem is a little less simple when the parallel lines of way between which it is required to establish communication are continuous, as is necessarily the case on main lines. The cross line of way on which the traverser runs is then on the same level as the others, or indeed on a slightly higher level, as has already been pointed out (255).

To allow of a traverser, carrying a carriage, being moved it is not sufficient

that the latter be brought upon the former and rest upon it; the carriage must also have been lifted vertically a height at least equal to the projection of the wheel-flanges below the rail-heads. It is in the means employed to effect this raising of the carriage, that the various types of "traversers on the level" differ from one another. The horizontal motion by which the carriage is propelled on to the traverser may precede the raising motion, or may be given simultaneously.

The hydraulic traverser, an appliance now abandoned on account of its complication, belonged to the former class. This traverser carried, not like the others a pair of rails, but a frame resting on the vertical piston rods of four small hydraulic presses. The traverser, brought between the rails of the line of way occupied by the carriage to be transported, left the circulation perfectly free on that line. On the carriage being brought just over the traverser, the pumps were worked by hand until the frame of the traverser, pressing on the axles of the carriage, had raised it so as to bring the wheel-flanges clear of the rails. On the traverser being taken to the line where the carriage was required, by the opening of a cock the water was allowed to flow away into the feed tank, and the frame descended leaving the carriage on the rails. The traverser, ran on a supplementary line of way not raised above the rest; its rollers were flangeless so as not to interrupt the rails of the main lines; and it was guided by four horizontal wheels gripping a central rail.

In those traversers where the action of raising the carriage and of propelling it forward are simultaneous, the traverser carries a short piece of line which instead of filling the gap in the main line, as is the case with traversers running in a pit, projects its rails vertically upon those of the main line.

Several arrangements have been attempted. Thus, in the carriage shed at the Paris terminus of the Lyons railway, the lines on both sides of the traverser could communicate either, on the level, with their continuation on the other side of the cross rails, or with the rails on the traverser. In the second position the difference of level was met by a suitable gradient given to the rails abutting on the cross line. These rails were moveable, at one of their ends, round a horizontal axis, and rested, at the other, on the side of the traverser rails, upon eccentrics worked by levers; but even this was a complicated arrangement out of all proportion to the result achieved; it also has been abandoned, and the rails are fixed in the position in which they correspond to the rails carried by the traverser.

314. A solution of the difficulty, after the fashion of the common dray, was proposed twenty years ago in Belgium; but not being practical, it has never

been carried out; it deserves to be mentioned, however, on account of its ingenuity, and as the idea might possibly be developed out in some more satisfactory manner (Pl. XXX, figs. 1 to 6). The platform, P, of the traverser is capable of tilting and forming an inclined plane, resting on the one hand on the rails bearing the carriage to be transferred, and on the other on a pivot, A,A, suspended from the axles of the traverser. On the top of the platform is placed a winch, T, by means of which the carriage is hauled up. When the centre of gravity of the whole of the moveable parts passes the axis A, the platform swings over and bears upon a cross-stay, E; the wagon extends a little beyond this position, in such a manner that the centre of gravity very nearly coincides with the centre of the rectangle formed by the four bearing points, and the traverser, then perfectly stable, is propelled along its line of rails by means of the winch, *m*, which by gearing works the pair of wheels.

It is probable, that the practical application of this apparatus has been deteriorated by an attempt to make it accomplish too many duties at once; the addition of a revolving crane, G, for loading, and of a weigh-bridge, *p*,*p*,*q*, have so complicated it as to entirely alter its character, and to deprive it of the simplicity which is indispensable in appliances of this nature.

315. At the present time the traverser is reduced to a kind of wrought-iron box, without any bottom, carrying at its sides two flat bars, as the rails of the moveable way, and on which the wheels rest by their flanges (Pl. XXXI, fig. 12). Although the lower faces of the flat bars pass as near to the rail as possible, a certain clearance is always necessary; so that the height to which the carriage must be raised is equivalent to the sum of this clearance, the thickness of the flat bars, and the projection of the flanges below the rails. This height should be distributed over an inclined plane of sufficient length.

Communication is often afforded between the flat bars and the rail by means of a tapered piece, *f*,*f*, in the form of a switch (figs. 9 and 10, Pl. XXXI), moveable either on a horizontal axis or on a hinge at a slight inclination from the vertical, which is pressed down on the rail when the wagon is being shunted on to the traverser, and afterwards raised or thrown back sideways on the box, so as to present no obstacle to its motion. These moveable appendages, being applied immediately to the rail, prevent any abrupt spring; but they get out of order, and, as they are not indispensable, it is better to do away with them, and to reduce the shock as much as possible.

Figs. 1 to 7 (Pl. XXXI) represent the traverser of the Eastern of France Railway; it is formed of two plate girders connected by cross braces, the outside ones of which carry the load on to the journals which are outside the wheels.

The load is not applied direct to the journals by brasses, but by friction rollers, g,g, an arrangement applicable to slow motions, and which greatly reduces the sliding friction. If r be the radius of the journal, R that of the rollers g, r' that of their shafts; the frictional distance for one revolution of the wheel is reduced from $2\pi r$ to $\frac{2\pi r r'}{R}$, that is to say in the ratio of 1 to $\frac{r'}{R}$. Hence $r' = \frac{1}{3} R$. The rails are formed of two angle irons, c,c (figs. 5 to 7) rivetted to the bottom of the girders, and which at the same time constitute an essential element in the rigidity of the latter. They terminate at each end in an appendage, P,P,P (figs. 1 to 4), forming an inclined plane, and affording a groove into which the flanges of the carriage-tyres enter; the wheels of the traverser being guided by flanges outside.

The traverser for passenger carriages on the Austrian State Railway (Pl. XXXI, figs. 9 to 16) is of a similar construction; its rails are formed of angle-irons, c,c (fig. 15), rivetted to the longitudinals; it differs from the preceding example : 1st in the fact that the counter-weighted inclined planes, f,f, are moveable; 2nd in the method of guiding the traverser. Its wheels, R,R, without flanges, revolve on a continuous line of way, the level of which is below that of the main rails to an extent equal to the normal projection of the flanges of the carriages. The rails, r,r, of the main lines are necessarily interrupted, at the crossing of the traverser line, for a length a little greater than the breadth of the roller tyres; but the carriage wheels, in passing over these points, bear with their flanges on the rails of the supplementary way, and on the pieces, F,F, forming inclined planes to avoid the shocks. The wheels of the traverser are guided by the guard-rails, C,C, of the same height as the rails of the main line, and to which they are united by angle pieces, e,e, bolted on. This arrangement is indeed a little complicated; and, in consequence of the small diameter of the traverser bearing wheels, the axles of which sustain the load direct, the working of the traverser is somewhat difficult.

CHAPTER XI.

MANUFACTURE AND DELIVERY OF RAILS.

§ I. — Remarks on the conditions required in specifications.

316. A complete treatise on the manufacture of rails would be almost that of the entire process of iron manufacture. This does not come within the scope of the present work; but, without entering into a profound dissertation on this subject, we cannot refrain from passing rapidly in review the conditions imposed by railway companies on manufacturers, as well as the progress effected in the production of rails during the past few years.

Rails are, as we have already remarked (132), under more favourable conditions than would at first sight appear. Under the influence, otherwise unexplained, of the passage of the trains, they do not become oxidised; but if they become destroyed merely by the performance of their proper duties, and more or less in accordance with the condition of the other portions of the permanent way, sleepers and ballast, and of the maintenance, this destruction, sometimes very rapid, does not proceed at a normal and necessary rate of progress. It is not wear; it is sometimes the upper table of the rail which becomes deformed and depressed without appreciable loss of substance; sometimes, and much more frequently, it is the metal which laminates and becomes detached in layers of greater or less length and thickness. In the former case the iron is too soft; in the latter, it is homogeneity and compactness in the material which are wanting.

If it were only a question of wear proper, its rate of progress would be very slow, almost uniform; and a certain relation might be set up between the duration of the rails and their loss of weight; but the nature of the deterioration to which they are subject excludes any relation of such a nature. An entirely local deterioration may necessitate the removal of a rail of which the loss in weight is but slight, while another, worn throughout its whole length, but

nowhere seriously, might be kept in use notwithstanding a much more considerable loss.

Let us mention in passing a singular circumstance noticed on the Northern of Austria Railway : it is that, other things being equal, the deterioration of rails is found to be much less rapid on a double than on a single line of way. It would seem that, with an equal traffic, this deterioration should be exactly double in the former case what it was in the latter. It is, however, found to be much less. We will not stop to enquire into this fact, although it would appear to be an established one from prolonged observations made on an important line of railway. May it be attributed to magnetic influence, or to lamination? The layers detached at one end, and gaping, being necessarily rubbed backwards, as it were, and broken off by the flanges of the tyres on single lines, while, on double lines, those which are encountered by the wheels at the point where they still remain attached to the rail are pressed down upon the rail during the passage of the train.

Experience has, besides, pronounced upon the degree of truth in the theory of molecular alteration, so long held as a menace over all solid wrought iron structures, without distinction, which are subjected to vibration. Now that the simultaneous increase in the weight of locomotives and their speed has augmented on certain lines the number of fractures of the rails, which had become too weak, many have put forward the explanation, by no means reassuring, of diminished resistance due to a gradual change in the molecular arrangement; the remedy has even been proposed and sometimes applied : viz, to anneal them. It is thus, they say, that a sudden stop was put, at a particular time, to the fractures which were repeated to an alarming extent on the line from Saint-Etienne to Lyons. But, while admitting the fact, one can observe in this circumstance, not a confirmation of the hypothesis in question, but simply a well known effect of annealing applied with the necessary precautions (without which the effect would be just the contrary); to render the iron less brittle and more ductile, but at the expense of its hardness. A system which makes rails soft when, at any cost, they are required to be hard, cannot be proposed seriously, and at the present day less than ever. It is not at a time when the practice of annealing has been unanimously condemned for railway axles, notwithstanding the example to the contrary set for a long time by several large carrying companies, that it can be seriously recommended for application to rails.

One thing, however, is certain, viz., that if the transformation under consideration really takes place with rails, its progress is so slow that it has nothing to do with the question of their durability.

The evil must be looked for either in the nature of the iron itself, or in the process of manufacturing rails. What is required is to make rails which do not alter in form, the elements of which do not become disunited, and which only wear away.

The control by which railway companies endeavour to guard themselves against a delivery of defective rails, or against its consequences, is exercised in different ways: 1st in the conditions of manufacture, and the supervision of their manufacture by inspectors kept permanently at the works; 2nd in the examination, and mechanical testing of the rails on delivery; 3rd by delaying the certificate.

The examination of rails on delivery needs no apology, but this system sometimes presents difficulties in practice; as a rail may be very good in spite of a few defects, more apparent than real, and the magnitude of which might be exaggerated by the inspectors. Tests are also necessary, as the most careful inspection is not sufficient to enable one to judge of the quality of the iron. But even in this matter the tests should have the effect of determining whether the rail possesses the qualities really useful for the work it has to do; and this is not always the case.

As regards the conditions of manufacture and supervision exercised at the works, their utility is at any rate open to question. Conditions of delivery which are really practical and strict, and a certificate which takes into due account the circumstances under which the rails are to be laid down, create at the works an incentive sufficient to cause the delivery of a good article; and, if it be good, what matters it how that article is produced?

The supervision exercised over works by those companies, that impose conditions not only of quality, but also of manufacture, may certainly possess its advantages. Doubtless a railway engineer may sometimes give a useful direction to the experiments of an iron-master, and cause him to turn to better account, both for his own advantage and that of the railway company, the raw materials which he has to work up. But for this, it is necessary not only that the engineer should become a metallurgist, but also that he should make himself thoroughly acquainted with the special conditions of manufacture at each establishment; that he should, in a certain sense, put himself in the place of the proprietor. No doubt this is not impossible, it happens sometimes, perhaps, but as an exception; the engineer who has to do with several works has an almost irresistible tendency to generalize the conditions of manufacture, to impose common rules, without taking into account difference of circumstances, of ores, and of fuels. If such a system has sometimes perchance induced progress, it has much more frequently placed trammels in its way. With more freedom in their mode of working, and in full possession of their

initiative, manufacturers should devote themselves, at their own risk, to those incessant experiments which are the condition, the very life, of industry. A state of things which throws the entire responsibility upon manufacturers, while it deprives them of their liberty, is contradictory to itself. Besides, if any one suffers, it is less the manufacturer than the railway company, which might often, there is little doubt, obtain, if not better rails for the same price, at any rate much better rails for a price but little higher than that paid.

It is only in France, that classic land of rules and regulations, that the liberty of manufacture has, hitherto, generally been denied. It has existed for a long time in England, in Germany, and in Italy; the Belgian government has also decided to eliminate from its specifications all stipulations tending to secure, not the quality of the manufactured article, but certain rules, the efficacy of which is often called in question :

" The contractor will be at liberty to adopt, for the operations of refining, rolling, " piling and welding, the method which appears to him best for the production of a " durable iron free from defect." (Specification of the 30th September 1866, art. 3.)

The Belgian Government only reserves to itself, by a perfectly reasonable clause, the right to know, if it thinks fit, how matters are being conducted :

" The government reserves to itself the right to follow, by its agents, the manufac- " ture of rails. Iron-masters will be required to give them, for this purpose, all the " information that may be demanded. The contractors can make no claim on this " account, even when rails which have been inspected during manufacture, may be " rejected for any defect."

Coming from a country in which the manufacture of rails has been so highly developed, this circumstance is full of significance. It is understood, in Belgium, that a specification can only be general on condition of its being silent as to the conditions of manufacture.

It is in this way, that the Belgian iron-masters have been able to attempt, and often successfully, the manufacture of rails entirely with puddled iron.

France is, moreover, beginning to adopt the same course. The new specification of the Orleans Company provides (art. 5) :

" The rails are of hard iron, thoroughly welded, not " cold-short ", of fine grained " iron in the head, and of a quality similar to that of the sample which has been " submitted by the contractor, and agreed to by the Company.

" On account of the special warranty (five years) which he has agreed to, the con- " tractor is permitted, if he think fit, to manufacture the rails to be delivered entirely " in puddled iron, or with such proportion of old rails as he shall think it advisable " to employ in the new rails."

The Orleans Company thus inaugurates a system which will doubtless soon become general, and which cannot fail to give good results.

312. The late and lamented M. Perdonnet, after having said (*), that he does not share the opinion of the author as to freedom in the mode of manufacture, adds a little further on (**) the following :

"If the relative value of the different processes were well ascertained, if the same " process could be enjoined for all works, whatever be the nature of the ore or the " pigs which they employ, we should uphold the process of manufacture adopted by " the Northern and Western of France Companies, and we should stipulate in the " specification that the process of manufacturing the rails should not be departed " from; as is the case with mortar in works of art. But at the present day, when " opinions differ as to the nature of the iron used in the composition of the piles, " when some consider that piled iron should be combined with puddled iron, and " others that it is best to employ only puddled iron, when some persons even, " notwithstanding the slight degree of success obtained by making the piles only of " bar iron, might be led to repeat the experiment; when some desire to give a " greater thickness to the slabs and others a lesser one; when, in fine, the " question of rail manufacture is still undergoing experiment, we are of opinion " that if the manufacturer consents to submit his processes to the approval of the " engineer in chief of the Company, the most advisable course is not to insert in " the specifications conditions which experience may induce one to modify."

M. Perdonnet in these lines combated, he says, the opinion expressed by the author in 1857 (***); might he not be thought to be supporting it?

"We have lately returned", says Mr Prokesch (****), Engineer in Chief of the Northern of Austria Railway, "to the more simple and reasonable plan of leaving the works free " to carry on the manufacture in the way they think fit, while at the same time hold- " ing them responsible for the quality of the rails by requiring an equitable gua- " rantee; which amounts to the same as testing the whole of the rails under their " actual conditions of the traffic to which they are subjected."

"An establishment", says Mr Sieber (*****), "which, by carefully refining its pig " according to rule, may manufacture good rails, may also sometimes turn out some " very bad samples by conforming to the terms of the specification."

313. An objection has been made to freedom in manufacture, that its necessary remedy is a prolonged guarantee which defers for a long period the

(*) "Traité élémentaire des chemins de fer", 3rd edition, vol. II, p. 104.
(**) Ibid. p. p. 106 and 107.
(***) "Chemins de fer d'Allemagne", p. 303, etc.
(****) "Zeitschrift der osterreichischen Ingenieur Vereins", 1866, p. 147.
(*****) "Mémoires des ingénieurs civils", 1864, p. 361.

settlement of accounts at the works; and which presents difficulties when, as is often the case, deliveries are made to a railway, where the various sections are under very unequal conditions as to nature of district and of traffic.

The first objection is without force, as the companies can, without risk, thanks to the well-known stability of the firms with whom they treat, arrange their payments before the expiration of the guaranteed term.

The Orleans Company, for instance, distributes its payments as follows (art. 16 of the specification).

" 85 per cent of the value of the rails passed at the works, in the course of the " month following their reception;

" 10 per cent of the value of the rails delivered at the yards, in the course of the " month following that of their reception;

" And the last five hundredths, a year after the commencement of the three years " guarantee."

This arrangement is still further modified by the following :

" It is nevertheless understood, that when the last five hundredths retained during " the guaranteed term shall amount to a sum of £2,000, this balance shall not be " increased, and the sum produced by the five hundredths exceeding that amount " shall be paid to the contractor at the same time as the second payment on account " of 10 per cent."

As to the second point, the guarantee works fairly and without confusion; by basing, the quality of the delivery not upon the whole delivery but on a portion of it, and upon samples sufficiently numerous to represent the general state, and placed under certain well defined conditions.

Instead of replacing the rejected rails, the contractor allows to the company a certain deduction. Thus a complete re-examination is avoided, where no account could be taken of the very different conditions presented by different sections of the same system, and also of the immediate renewal of rails which, notwithstanding their defects might still do duty for a longer or shorter period.

The following is the rule laid down by the specification of the Eastern of France line (art. 14):

" The company will only accept rails which can, without any deterioration on the " principal portions of its system, last three years; it will satisfy itself, by partial " experiment, that this condition is fulfilled.

" The contractor consequently undertakes to submit to a reduction from the " contract price and on the whole of the delivery, proportionate to the number of " rails which shall not stand the test under the following conditions.

" At least 10 per cent of the quantity delivered, taken at different times during

" manufacture, at the option of the Company shall be laid down by them on such " portion of their line as they shall fix upon. An official certificate shall be given " to the contractor of the site and the date of laying the rails.

" At the expiration of three years service, both parties shall together determine the " proportion of damaged rails; that is to say, where deterioration has commenced, " such as crushing, insufficiency of welding, lamination, fracture, cracks at the fish-" joint, etc. This proportion shall be applied to the whole of the delivery, and " shall serve to determine the number of tons liable to the deduction, whether the " whole or only a portion of the delivery shall have been laid down (*).

" The rate of the deduction is fixed so as to represent the difference between a ton " of new and a ton of worn out rails, the rails to which the deduction applies " remaining the property of the Company."

These provisions are based upon the specification of the Northern of France Ry. which however clearly indicates (art. 13) the sections on which the rails to be passed must have been in use for two years without undergoing deterioration; viz, between Saint-Denis and Creil via Pontoise and via Chantilly, between Creil and Amiens, between Creil and Erquelines, and between Amiens to Lille and Valenciennes.

The conditions of the guarantee are defined by the specification of the Belgian State railways in the same terms, except as regards the following points:

" 1st Rails laid on the main lines at stations are alone excepted from the guarantee. " No exception is made in the case of curves and inclines (which are rare, however, " on the Belgian State railways).

" 2nd The contractor has the option of supplying new rails to make up the amount " of the deduction, by taking as a basis the rate of the last public contract let " at the expiration of the guarantee.

" 3rd The government reserves the right, in case it considers, that the rails cannot " be retained in use during the three years of trial, to fix at any time during the " interval, the partial deduction due under this head by the contractor, and to require " of him, before the expiration of two months, the payment of this deduction; the " amount of which shall be provisionally determined in accordance with the latest " contract-prices."

On the Paris and Mediterranean system the period of guarantee is likewise three years. The proportion of the delivery tested is reduced to $\frac{1}{20}$, and the portions of line on which the trials are made are not to have a steeper gradient

(*) The former specification contained a saving clause couched in these terms: " It is, however, understood, that the rails subjected to this test will not be laid down at stations, nor in parts of the line on a curve of less than 25 chains radius, or on a gradient steeper than 1 in 100." This clause has however been omitted from the present specifications.

than 1 in 100 (art. 10 of the specification). In accordance with article 11, the payments are made as follows :

"95 per cent of the value of the rails delivered, during the month following the "delivery; and the five last hundredths, after being finally passed, that is to say "after the deduction representing the minimum value of the defective rails is made."

§ II. — Manufacture of Iron Rails.

319. 1st General observations. — There has been much discussion as to the texture of the iron required in rails.

It is a fine-grained iron which is most generally recommended; the question is, be it well understood, of a grain inherent in the iron itself, so to speak, and not of that which results from an incomplete refining, injurious to the quality, if the pig be impure; neither is it a question of the grain, coarse and irregular, presented by burnt iron. Fibrous iron, often specified for the fort (*), seldom for the whole section excepting the top slab, is most frequently only tolerated at the present day, and then only partially so. The unequal headed rails weighing 78 lbs to the yard, ordered by the Italian Government from the Seraing Works, for the incline between Pontedecimo and Busalla on the Turin and Genoa line, came under the former category; out of the eight layers which composed the pile, fibrous iron was specified for the six last.

The coarse-grained, or, to speak more correctly, crystalline iron, which owes this texture, as is well known, to the presence of silicon, sulphur, and phosphorus, is generally rejected. As however many ores now yield a considerable quantity of coarse-grained iron, unsuitable for many purposes, manufacturers have sought to introduce it into the rail market; it appears, indeed, suitable for forming a hard and homogeneous head. Experience has proved, as a rule, that the iron obtained from phosphorous ores is suitable for the slabs. The phosphorus renders the metal more easily welded, and it counteracts the hot-short tendency due to the sulphur, and which is the cause of cracks.

But if the pile contains fibrous iron, as well, it is difficult to effect an intimate union of the two classes of iron of such different nature. The first,

(*) As Herr von Tunner (*a*) remarks, the foot, more drawn out than the head, has a tendency on that account even to a fibrous arrangement of molecules. The conditions imposed by some engineers are thus approached by the mere fact of the mode of manufacture, and independently of difference in the nature of the iron.

(*a*) *Ueber die Walzenkaliberirung.* — Arthur Felix, Leipzig, 1867.

softened and consequently capable of being welded at a low temperature, is near its point of fusion when the second has not reached a temperature suitable for welding; so that, if this temperature be approached, the granular iron becomes burnt, and, if only a lower temperature be attained, the weld is imperfect.

A skilful and attentive furnace-man can, however, take advantage of the different temperatures in the irons to be reheated, and so bring each of the two kinds of iron to nearly the degree of heat desired. The mixed pile should always be placed, in the re-heating furnace, with the top slab on the bottom. The fibrous iron, exposed to the flame, is heated to a higher degree. When the pile has become in some degree united, it is placed sideways with the fibrous iron towards the grate-bars. It then becomes heated to a still higher degree, while the granular iron is shielded from the direct action of the flame. The thicker the slab of granular iron, the longer time does it require to attain a welding temperature; and during this time the fibrous iron is gradually attaining the temperature suitable to it. If, then, the French specifications now for the most part refrain from requiring fibrous iron in the foot of the Vignoles rail, it is often with reason that they admit it, as the production by puddling of a more or less high proportion of fibrous iron cannot be avoided, especially with some classes of pig.

The usual average length of rails at the present day is 19 ft. 6 ins. With a weight of about 75 lbs to the yard, a greater length would require piles difficult to be handled and heated evenly. This weight has, however, been exceeded in England, in Belgium (*bb*), and even in France but only with the Barlow rail on the Southern Line, which was also 19 ft. 6 inches long and weighed nearly 91 lbs to the yard.

The weight of rails is generally specified at the same time as their section. In order to be perfectly concordant, these two stipulations should take into consideration the difference of specific gravity, which varies especially with the structure of the iron. Thus it has been ascertained, that on the Rhenish Railway the weight of rails rolled out of fine-grained iron appreciably exceeds that of rails from fibrous iron, which are, in turn, heavier than those from coarse-grained iron. If then the manufacturer employs harder iron than he intended, it is necessary, in order not to suffer loss, that he slightly reduce the section, the allowance (*) moreover, intended to make up for

(*) This allowance is generally 2 per cent for partial deliveries, but is reduced to 1 per cent on the whole delivery. Above this proportion, the excess of weight is not paid to the contractor; below it, the whole of the delivery is rejected.

slight and inevitable variations in section, not always allowing a sufficient margin, if there be, besides, differences of specific gravity.

Let us now cast a rapid glance over the rail manufacture: 1st in France; 2nd in Belgium; 3rd in England.

330. 1st France. Let us first remark a negative character in this manufacture. No mention is made, as a rule, in French specifications of hammering, either in the case of puddle-balls (although, it always takes place, the other appliances for shingling not being in use in France), or in the case of piles for slabs or for rails. The use of the hammer was, however, provided for in the old specification of the Paris Suburban line (art. 3), but in these terms:

"The engineer charged with the duty of passing the rails may require that the piles "for rails be welded under the hammer, if welding between the rolls should not "appear sufficient."

It is evident that so stringent a condition could not be left to the judgment of the engineer; but the hammering of the piles is certainly one of the greatest guarantees of the quality of rails, and, as conditions are imposed, this is one of the most important; but, if imposed, it must also be paid for.

This practice of hammering has been adopted in France, for instance at Decazeville (Aveyron) in 1863. The pile was hammered under a 5 ton steam hammer, and drawn out until it could pass through the first finishing groove. The hammer thus entirely replaced the cogging rolls. Sometimes the bar would even enter the second finishing groove at once.

Hammering requires care; the first blows should strike on the slab, passing from the middle towards the ends, in order to extract the slag. They should be sharp and quick, so as to weld the pile while it is still hot. Heavier blows then draw out the bloom from a fourth to a third of its length. If some layers should become detached while hammering on edge, it is necessary to take another heat and again resort to the hammer for welding. After hammering the bloom is re-heated, but moderately, so as not to burn the granular iron.

As a rule, in rail mills, the three first grooves effect the weld, the temperature of the bloom being sufficiently high; the fourth is the first sectioning groove; if there be an attempt to compress the substance earlier, the projecting parts of the slabs, imperfectly welded, would separate.

The top slab is generally in a single piece. The head of the rail being less compressed than the web, it was feared, if a joint were admitted, that an

imperfect weld would be obtained at the very place where continuity is most necessary. This condition of a single slab, which has however been departed from in certain cases (330 and 331) leads also, to a certain point, to that of the use of piled iron, it being difficult to obtain puddled bars at once wide, thick, and sound at the edges.

321. One difficulty, especially when attempted to be carried out in its most radical form, has been the idea of rolling rails out of puddled iron : viz, to roll a puddle-ball, formed of a single mass, shingled, drawn out under the hammer, and then re-heated. A rail may thus have been obtained without weld; but this process, sufficiently difficult of application when short rails of small section are concerned, becomes literally impossible in the case of the rails of the present day, averaging 19 ft. 6 ins. long and weighing about 75 lbs to the yard; at least not without radical alterations in the furnace and in the very operation of puddling. The advantage is, however, sufficiently great to justify a little perseverance on the part of manufacturers, and a little toleration of a few defects on the part of railway companies. The idea has, however, not been entirely abandoned. The Dowlais works sent as a specimen to the Exhibition of 1867, a large puddle-ball obtained from a reverberatory furnace with revolving bottom, and intended to be converted into a rail at a single heat. But the furnace of which we speak is not yet in practical operation; its maintenance is too costly. Herr Borsig, again, exhibited puddle-balls weighing 5 cwt., and over, obtained from a reverberatory furnace provided with two working doors, which permit of four men working at once. Other puddle-balls, also obtained, it is said, at a single operation even reached a weight of nearly a ton. But the production of these balls can only be regarded as exceptional feats, without practical value in masses of such size which cannot be thoroughly freed from slag by the hammer; within narrower limits these experiments would be interesting, no doubt, as evidences of future progress, since, especially as regards rails, attempts are now being made in another direction, viz. the economical production of refined cast metal (347).

322. The piles for Vignoles rails, with which we are here most concerned, are generally made of piled iron in the head and flange, and of puddled-bars inside. The conditions are more or less explicit and minute, as to the composition and arrangement of the piles for the slabs, and for the rails.

They are thus expressed in the specification of the Northern of France Railway :

Art. 6. The rails are to be of hard and homogeneous iron, thoroughly welded, not

cold short, of fine grain, especially in the head; in fact of a suitable quality to stand the action of the wheels without breaking, splintering, laminating etc.

Art. 7. The manufacture of the iron shall be conducted so as to obtain, as far as possible, only fine-grained iron.

The puddle-bars intended for making the rails shall be, moreover, classed by their nature, under three distinct heads, viz: — 1st granular iron; 2nd mixed iron, or granular combined with fibrous; 3rd fibrous iron.

In the pile for fagotting, only iron of the first-named class shall be included; that is to say, granular iron.

The piles for the rails shall be composed as much as possible of fine-grained iron. In any case the fibrous iron shall only be admitted in the last third of the pile; the mixed iron shall be placed between the fibrous iron and the two first bands of granular iron.

The bars forming the different layers shall be of rectangular section. Each layer of puddled iron shall be composed in breadth of two or three pieces at most. The layer of piled iron forming the upper portion of the pile shall be in a single piece. It shall represent in weight about one-fifth of the total mass, so as to present in the section of the finished rail, a thickness of at least $\frac{3}{8}$ inch on the wearing surfaces.

The rough ends of the bars forming the piles shall be sheared off. These bars shall all be of a single piece, carefully arranged throughout the whole length of the pile. In the case of the puddled iron, however, a few bars in two pieces, at most, may be admitted, the smaller of which is not to be less than 12 inches long; but in that case they are to be carefully fitted together, end to end, so as to leave as little empty space as possible inside the pile. The layers shall be arranged so as to break joint; to this end the puddle-bars shall not be of the same width.

The new specification of the Eastern of France reproduces the same conditions and in the same terms. It requires, however, only about $\frac{1}{6}$ of the weight of the pile to be of piled iron (instead of $\frac{1}{5}$); a proportion considered sufficient to ensure the thickness, always required, of at least $\frac{3}{8}$ inch at the wearing surfaces; and it adds:

This last condition shall be tested in the finished rails by the action of acid.

This very simple method of verifying the arrangement of the layers under the action of the rolling mill is often employed.

Several examples of its application are represented at figs. 17, 18, 19 and 20, of Plate II, and 10 and 11 of Plate III.

The old French specifications required, in double-headed rails, a much greater proportion, $\frac{1}{3}$ at least, of piled iron (Paris Suburban Railway; specification of the Eastern Railway, 27th Dec. 1851; Southern Railway, specification of 19th July 1855).

The Southern of France Company has retained this proportion; with this exception, the conditions are the same as those of the Northern and Eastern

of France lines. Fibrous iron is also admitted, but only in the centre of the pile, since the rails are double-headed. Not more than the third part of the pile should be composed of fibrous iron (art. 7).

The Paris and Mediterranean Company also requires one third to be of piled iron whatever be the section; but the conditions which it imposes differ considerably from the preceding :

The foot of the Vignoles rail, like the head, is to be formed of a single slab of piled iron.

Ores which yield brittle iron should not be charged into the blast furnaces used for the production of the pig iron intended for the manufacture of rails.

The breadth of the rail-piles is nearly 8 inches, and the height 8 ½ inches at least; empty spaces not included.

The piles for rails and for cover slabs, of piled iron, must be exclusively composed of rectangular bars, laid together on their flat sides in layers of regular thickness, and in such a manner as to break joint.

The piles for covering slabs are to be rolled flat-wise and not on edge, so that the breadth of the covering slab be parallel to the direction of the bars composing the covering slab (art. 4 of the specification).

If, as in the case of the Vignoles rail, the fibrous iron is admitted at the base of the pile, it would have been natural to recommend the use of mixed iron instead of simply permitting it; since, in forming a gradual transition from fibrous iron to granular always required at the top, it diminishes the chances of a defective weld, almost inseparable from a sudden change in the nature of the iron. Fig. 14, Pl. XXXII, shows the composition of the pile for the Vignoles rail of the Northern Railway, manufactured more than ten years ago in the Anzin works and the blast furnaces of Le Nord, the welding of which, according M. Alquié, was very satisfactory :

a. Granular piled iron.
b. Puddle-bars of granular iron.
c. Puddle-bars mixed with granular iron.
ddd. Fibrous iron.
ee. Fibrous piled iron.
Length of the pile : 3 ft. 9 ins.

		cwt.	qrs.	lbs.
Weight of piled iron . . .	Fibrous covering slab.		3	15
	Fibrous vertical bars.		2	16
		1	2	3
Weight of puddle-bars.		3	3	25
	Total.	5	2	0

In order that two classes of iron may weld together easily and well, it is

necessary that they not only have the same amount of working, but also that they be of the same nature and the same texture. Several engineers even regard the latter condition as more essential than the former, a circumstance which diminishes in their eyes the interest which, according to others, is attached to the manufacture of rails entirely of puddled iron.

But, though not constituting the only obstacle to a good welding up, the presence of the re-worked iron in the pile is no less an actual obstacle; and a pile entirely homogeneous, both as regards texture and the degree of working it has received — that is to say, composed entirely of puddled granular iron — would present, as regards the very essential point of welding, undoubted guarantees.

It is not, however, in France that these experiments can be undertaken and carried out with sufficient persistance. It would be necessary to submit to the requirements of specifications, and to abstain from tests the result of which, even if favourable, might be perhaps accepted with difficulty. Besides, the experiments made at several works, Maubeuge and Montluçon among others, were soon discontinued.

Greater perseverance was however manifested at the Providence works, Hautmont. Fig. 17 represents a pile from these works for a Vignoles rail, almost without piled iron :

	cwt.	qrs.	lbs.
1, soft piled iron.		2	15
2, 2, mixed puddle-bars.		2	23
3, 3, 3, puddle-bars.	3	3	25
	5	1	7
Weight of the rail.	4	0	26
Weight of the crop ends.		2	16
	4	3	14

Loss 49 lbs, or 8.2 per cent.

Without being so explicit as that of the Orleans Company, the specification of the Western of France is more so than that of the Northern and Eastern; the use of piled iron is not expressly specified; but it requires that the top and bottom slabs of the rail pile shall be each in one piece, and shall form one fourth of the weight of the pile. They must be produced from puddle-balls shingled under the hammer, and then drawn out betwen the rolls, either with or without re-heating; they must also consist of fine-grained iron, and preserve this grain in the fracture of the finished rail. The inside bars of the pile must run the whole length and be arranged so as to break joint the pile must be at least $11\frac{3}{4} \times 8\frac{1}{2}$ inches sectional area.

323. As the peeling away of the edges of the head is the most usual defect in rails, an endeavour has been made to counteract it by doing away with joints in this portion. The covering slab, of piled iron, is in that case provided with edges somewhat turned down. This form was adopted, for instance, at Creusot for the unequal headed rail of the Paris and Mulhousen line, and in 1862 at Fourchambault (Nièvre) for a uniform double-headed rail. Fig. 13, Pl. XXXII represents the pile (*h*, *h*, *h*, puddle-bars; *c*, *c*, piled iron). But this arrangement has only achieved middling results. It is in fact opposed to the expulsion of the cinder, which, finding no outlet, accumulates in the corners. It has, however, recently been resumed for steel-headed rails manufactured at Grätz in Styria (342), and also for rails with unequal heads made at Terre-Noire and intended for the Italian railways. There are, besides, in the base of the pile, in the latter cases and also in that of the Vignoles rail, only two small bars of piled iron forming the edges of the smaller head.

324. The piles for covering slabs are almost always formed of flat layers. At Styring (Moselle), however, the bars are arranged on edge. According to M. Alquié, this arrangement would be preferable, as one or two defective welds would have but little effect on the whole, while, with the bars arranged flat-wise, a bad weld renders the whole covering slab defective.

325. Mechanical puddling, introduced by M. Dumény, and M. Lemut (formerly pupil in the Ecole de Mines), at the Clos-Mortier (*) Ironworks, and tried with success at Hayange and Moyœuvre (Moselle), has also been applied recently to six large puddling furnaces at the Styring works where it is in regular operation.

326. The rail pile is drawn out, sometimes at a single heat, and sometimes with an intermediate re-heating between the passes through the cogging and the finishing rolls. Thus, at Alais (Gard), the double-headed rails of the Lyons railway, weighing 73 lbs to the yard and 16 ft. 6 ins. long, have been rolled without a fresh heat. They passed through four angle or corner grooves in the cogging rolls, and through five sectioning grooves in the finishing rolls. The pile weighed 4 cwt. 1 qr. 18 lbs; that is, 3 cwt. 2 qrs. 4 lbs, for the finished rail, 2 qrs., for the crop ends, and 1 qr. 14 lbs, for waste.

(*) "Annales des Mines", vol. II, p. 135 and vol. IV, p. 505 (1863).

At Horme (Loire), the pile is also rolled at a single heat. At Terrenoire and Fourchambault a fresh heat is necessary.

337. *Use of crop ends, and of rejected or worn out rails.* — The introduction into the piles of the crop ends of rails (329), as well as the working up of rejected or worn out rails, constitutes an important problem and one which is not without difficulty.

The practice of rolling rails into flat bars after a heat has been adopted at Alais, both in the case of double-headed and Vignoles rails. This costly operation may be dispensed with by interposing bars of special section in the spaces (figs. 18 and 24).

As the rails are usually sawn hot, advantage is often taken of the heat remaining in the crop ends to flatten them out; but it is not sufficient to reduce the heads to the thickness of the web, as the only result is bars thickened at the ends (Pl. XXXII, fig. 27), with spaces in the middle in which the cinder accumulates. Besides, with non-symmetrical rails, there is generally a difference between the head and the foot; one being granular and the other fibrous. The piles in which the rail ends are inserted without previous rolling scarcely escape the same inconvenience, notwithstanding the bars of special section with which the largest spaces are filled.

The Alais works had in 1861 and 1862 to deal with Barlow and Brunel rails taken up on relaying the Southern line. These rails before their introduction into piles. whether for covering slabs or for rails, underwent the following operations.

1st *Barlow rails.* — Incisions were cut in them round their whole surface at distances of a little over a yard apart, and were broken in a hand press; the pieces were placed, from twenty to twenty-four in number, for about an hour, in a heating furnace, and then taken out one by one and flattened (figs. 15 and 20) under a steam hammer, which is far preferable to the rolls employed for this purpose at Besseges (Gard); the former producing straight lengths regularly flattened, while the latter turn out curved pieces, and aggravate the defects of weld. In twelve hours ten charges, or about 210, ends were obtained.

2nd *Brunel rails.* — These rails of a smaller section, were cut cold at once by means of large steam shears; but the cuts were wanting in cleanness and regularity. The pieces were heated and flattened under the hammer (figs. 15 and 20) at the rate of 240 in 12 hours; it was only when the hammer was otherwise engaged, and the medium mill idle, that the latter was used for this

purpose, by passing the pieces one by one through two grooves. Eleven to twelve hundred were thus flattened every twelve hours.

WEIGHT OF THE PILES.

For covering slabs (fig. 15).

	cwt.	qrs.	lbs.	cwt.	qrs.	lbs.
Layers of puddle-bars.				2	1	12
2 " " Barlow rails.	1	2	26	2	1	4
1 " " Brunel rail.		2	4			
Total.				4	2	16
Or, per cent :						
New iron..					»	49
Old iron.				»	»	51
Total.				»	»	100

For rails (fig. 20).

	cwt.	qrs.	lbs.
2 cover slabs of piled iron. . . .	1	2	8
4 layers of piled iron ½ in. . . .		2	4
2 puddle-bars, 4 ins.		2	16
2 layers of Barlow bars.	1	2	26
1 layers of Brunel bars.		2	4
Total.	5	0	2
Or per cent, taking into account the old rails in the slabs (see the other side).	cwt.	qrs.	lbs.
New iron.		»	40
Old rails..	»	»	60
Total.	»	»	100

According to M. Surell, the Government engineer in chief of the Southern of France lines, these rails seem to be quite as thoroughly welded, as those made entirely out of new iron; and the amount of wear proved to have taken place up to the present time in the rails of the two classes, laid down at the same time and under the same conditions, tends to show that the insertion of the old rails in the pile has no influence, either good or bad, on the quality of the rails made at Alais.

328. *Straightening.* — The rails do not leave the mills perfectly straight. They present accidental deformations, to remove which advantage is naturally taken of the heat of the rails, they are struck with a beetle on a straightening bench, flat for double-headed rails, but curved for others. If the latter were straightened while still hot, they would become curved on cooling; as in the unequal-headed rail the upper table cools more slowly than the lower on account of its smaller sectional area, or than the flange of the Vignoles rail with its larger surface but equal sectional area. If the rails were made straight while still hot the head would have a higher temperature than the flange; so that, after cooling the upper table becoming shorter than the lower, on account of its greater degree of contraction, the rails would become concave upwards. The rail should therefore be struck upon a convex gauge or bench, in order to acquire the exact curve which would disappear after cooling. To determine the curvature of the template, a certain number of rails are

straightened out on a even surface and the curve they have assumed after cooling will give that of the gauge.

When cold certain irregularities in the rails are corrected. For this purpose any percussion is forbidden by the specifications. Pressure should be exercised by means of screws, so as to gradually impart to the metal the deflection corresponding to the permanent depression which it should preserve.

229. The rails must have both extremities cut off: several specifications fix the minimum length of the crop ends, a wise precaution, as defective welds especially exist at the ends of the pile. This minimum is generally 12 inches. Some Companies (the Lyons and the Orleans) require only that "the rails be cut off at a sufficient distance from the rough ends, for the two extremities to be perfectly sound."

It is always expressly forbidden to reheat any portion of the rails after *rolling*, whether for removing the ends or any other purpose: except during the *momentary derangement of the machine for cutting off the ends*, and then *only during the time strictly necessary* for reinstating it.

The Southern of France allows "cutting off, either cold by the lathe, the *planing machine*, or the slotting machine, or hot on leaving the rolls. In the latter case, if the saw be employed, the faces should be afterwards *tool dressed*." The Eastern of France specifies in addition, that the upper *edge of the head* shall be taken off, so as to form a chamfer of nearly $\frac{1}{16}$ *inch for the purpose of preventing* lamination (122). The Northern of France is *content to* stipulate that the ends be cut off "by some mechanical means *approved of* by the Engineer." The Lyons Company only admits of the *operation being performed* cold in the lathe, or by the planing machine. The *Orleans Company* require the use of the lathe or the shaping machine for one of the ends at any rate. It therefore only admits of the rails being sawed hot at one end.

230. ***Belgium.*** — The large iron works in the Charleroi and Liége basins divide their products between internal consumption and exportation. With foreign specifications they accept, the conditions therein contained; but, when they work for the Belgian Government, or for Companies, who adopt the same system, they avail themselves of the liberty allowed them.

Thus, the Couillet, the Monceau-sur-Sambre and the Montigny works have delivered to the Belgian State railway, some very sound Vignoles rails, without any piled iron, except at the edge of the foot, so as to avoid cracks.

It should be remarked, that at Couillet the top slab, extending the whole breadth, is formed of a kind of intermediate iron, refined with a greater amount of loss. The balls are shingled by a helve, which is preferable to a steam hammer. Each of the trains, of roughing and of finishing rolls, has six grooves. The pile therefore is subject to at least twelve passes; for, when it leaves a groove with difficulty, it is run through a second time.

Since 1860, the Montigny works, near Charleroi, have delivered rails to the Vienna and Warsaw Railway, which contain piled iron only in the foot (Pl. XXXII, fig. 16). The top slab is formed of three layers, while there are only two in the body of the pile. Far from the two joints in the slab being a cause of apprehension, they are regarded as a guarantee of quality, because they allow of the escape of the slag. It is a question of the higher or lower welding nature of the iron. However, this fact is only mentioned here to show the differences which exist; often, if not always, reasonable, and which prove how much value, in such a case, there is in absolute and uniform rules :

a,a. Granular puddle bars.
b,b. Fibrous puddle bars.
c,c. Piled iron, or more generally rail ends re-heated and rolled.

At Chatelineau, Vignoles rails have been rolled for the Belgian Government without any bars of piled iron. The foot has one it is true, of but a slight breadth, (not quite 3 ins); two layers of piled iron have been considered necessary for the wider rails ($4\frac{5}{8}$ ins) of the Northern of Spain Railway (Pl. IV, fig. 38).

The pile passes six times through the roughing, and as many times through the finishing rolls. The grooves are turned almost entirely out of the lower roll, except in the case of the last finishing grooves; otherwise there would have been too great differences of speed, especially with regard to the cooling of the foot. The pile on leaving the grooves of the cogging rolls, is of the following sectional area : $45\frac{1}{2}$, $37\frac{1}{2}$, 31, $24\frac{1}{2}$, $19\frac{1}{4}$, and 15 square inches.

Other iron-masters do not avail themselves of the liberty to dispense with the piled iron, but they reduce its thickness. Thus at Thy-le-Château, the top slab, of granular piled iron, is only one inch thick, and $7\frac{1}{2}$ inches wide. The puddled bar placed next is of granular iron, of the same nature as the top slab. It must be acknowledged, that the method of manufacturing these rails is justified by their quality. Those delivered by the Thy-le-Château works to the Northern of France Railway Company, and which contain the proportion of piled iron stipulated in the specification of this Company, last very well.

At the expiration of a warranty of three years, the proportion of rejected rails, deducted from those under trial, being $\frac{1}{10}$ of the whole quantity laid down between Namur and Liége, was 2·06 per cent for one delivery, and 1·16 per cent only for another. It is true that these proportions were slightly lessened by a concession gracefully accorded; as only sufficient of the standard short rails (16^{ft}.9^{ins} and 13^{ft}.9^{ins}), which could afford sound pieces, were included in the rejection, to balance the pieces of line taken up, although the specification made no distinction in this respect. The contract price being £6·13·7 the ton, and the sale price of the worn out rails £4·1·7. The indemnity was fixed at the rate of £2·12·0 per ton of rails rejected, in addition to 4^{s} for cutting, drilling, and incidental expenses, per ton of short lengths. These rails, we may add, are of coarse grained iron. Many others are so also, and are none the less good on that account. The stereotyped condition of a fine grain is, like the other general stipulations, sometimes at fault.

The specification of the Belgian Government, contrary to the French ones, abstains from any stipulation as to the method of taking off the rails ends. It provides simply that the section shall be "perfectly clean and at right angles to the axis of the rail."

331. *Germany.* — There is at the present time in Germany a double tendency, on the one hand to uniformity of section, and on the other to liberty in the process of manufacture. The period may be foreseen when, the production of rails having returned to its normal conditions, those of a regular manufacture like that of merchant bars, it may follow a steady course, and thus escape the alternate periods of prolonged stoppages and of urgent orders, through which it has so often had to pass.

This tendency of the German Railway Companies to efface conditions of manufacture from their specifications is so much the more remarkable, as but a few years back, some of them went further than was done in France in the matter of stipulations as to details. Thus, the specification for a batch of rails, delivered in 1861 to the Saarbrücke Railway Company by the Neukirchen works, forbade the use of a puddling furnace with air circulation, in use until that time; and required that the puddling should be accomplished in a furnace with water circulation. The intention of this provision was to overcome the ordinary defect in rails, the lamination of the heads. But, if the furnace with water circulation, in which the fusion is slower, and the working hotter, be in certain respects more suitable for the purification and regular decarbonization of the iron, it increases on the other hand the consumption of fuel and the loss. Both these apparatus may therefore give

either good or bad results; it was however singular to afford manufacturers a choice, the effect of which was drowned, so to speak, in a multitude of other predominating influences, and which, besides, is by no means indispensable to the quality of the product.

The same specification imposes the following conditions:

1st That the puddled balls be shingled by the steam hammer.

2nd That all the bars be broken and sorted, and those only admitted which are ascertained to be suitable for rails; those of fine-grained iron being reserved for the head and those of fibrous iron for the web and the foot.

3rd That the rail-pile be drawn after a single heat, then reheated and rolled into rails.

This programme is moreover remarkable; in that, starting as the French specifications do, and even more resolutely, with non interference of the Railway Company as to the details of manufacture, it adopts a principle of quite opposite character. Instead of the association of two classes of iron with different degrees of purification, one class only is relied on in this case, and not unreasonably, as the true guarantee of a good welding up.

Homogeneity, as complete as possible, is, moreover, the characteristic of the stipulations of several German Railway Companies.

The Thuringian Railway Company has sided against mixed piles; requiring, only one and the same class of iron without any other condition, but that the pile be hammered. It has been led to adopt this course by the observation of a batch of English rails delivered in 1846, formed entirely of puddled bars, and which had experienced in this long time a considerable wear of surface without any lamination.

The Berlin and Anhalt Railway Company adopts the same course, and for the same reason. It formerly required of the manufacturer, that there should be three different kinds of iron in the pile. Without being absolutely bad, the result was inferior to that obtained with English rails formed of a single kind of iron; and which were only replaced on account of their diminished sectional area.

The Westphalian Railway Company has been content for a long time (1858) to make no further stipulations than the hammering of the rail piles, and a warranty of three years. Others recommend "an uniform texture; so far as this uniformity is reconcileable with the hardness required in the head, and the tenacity required in the foot". A timid and insignificant wording; the uncertainty of which leaves tests and the warranty, as the only effective conditions.

For the condition originally imposed of having granular iron in the head and fibrous iron in the foot, some Boards have substituted that of the exclusive

use of fibrous iron. Such is the case with the Wurtemburg and the Baden Railways; who look upon homogeneity as the chief point, and consider that it is better ensured with fibrous than with granular iron, as the former more easily supports a high temperature. The Eastern of Prussia Railway, which has adopted the same system by way of experiment, has not found it answer. This may be easily understood; the head should undoubtedly be properly welded up, but, as it should also be hard, it is at least somewhat strange to have it of fibrous iron. If complete homogeneity be good in itself, it is with granular iron alone, and not with fibrous iron alone, that it must be expected. Fibrous iron in the head does not stand the test; and if it be of any use in the foot, it is at most with impact tests, which are generally stipulated in an incomplete manner and without limitation as to deflection (336).

The Rhenish Railway Company, which had also for a few years adopted a pile containing fibrous iron only, has now given it up; but only to return to the old practice, that of the mixed pile with reworked iron.

By giving a great thickness to the top slab of piled iron, the drawback of a bad weld with the rest of the pile is avoided, this weld being removed from the part where there is the most strain; but a very thick bar, formed of several layers, might notwithstanding the amount of working to which it has been subjected, possess in itself a defective weld. A dread of this has for some years led the Thuringian Railway Company to replace the top slab by bars set on edge, seven in number; the middle one being much thicker than the others (Pl. XXXII, fig. 11). The head is thus formed entirely of the same iron, and is connected with the body of the pile by the joints crossing (fig. 12). This method adopts, both the principle already followed at Styring (324), and that of joints in the top slab (330). It has been employed in England for a long time, but it has been abandoned, says M. Bineau (*), "because it has been ascertained, that the edge of the head may easily be broken." Up to the present time, the rails of the Thuringian Railway stand well.

The manufacture of rails, almost entirely from puddled bars, has considerably increased in Germany as in Belgium. The Bourback Works, near Saarbrücke, have made some rails for several railways with only piled iron at the edge of the foot.

At the Phœnix (**), Rhenish Prussia, as at the Couillet works (330), the top slab is in a state intermediate between piled and puddled bar. It is obtained from phosphorous ore, yielding a hard granular iron, cold short, but not red

(*) "Chemins de fer de l'Angleterre", page 20.
(**) M. Desbrière. — "Mémoires de la Société des Ingénieurs civils", 1858.

short; and consequently not giving rise to cracks in rolling. The ball for the top slab is shingled for five minutes under a 3 ton steam hammer, as it has then become too much cooled to pass at once through the rolls; it is reheated, but only to the temperature strictly necessary, to a cherry red. It has not then been actually piled; its percentage of carbon and of silicon, and its welding temperature. are not sensibly altered.

The top slab is sometimes of the whole breadth, and sometimes has two joints. which some companies require for the reason given (330). The layers next to the top slab are hammered for three minutes only, and rolled immediately without reheating. The rest of the pile is formed of fibrous puddled iron except two bars of piled iron (*b*, *b*) (Pl. XXXII, fig. 19), for the edges, and sometimes also four others bars *c*, *c*, *c*, *c*, obtained from flattened crop ends of rails. A special furnace receives four piles at a time. The top of the pile is placed on the hearth, so as to avoid heating the granular iron too highly. The pile, raised to a white heat, is hammered on its two faces, and drawn out for a period of seven or eight minutes under the 3 ton steam hammer. The bloom is reheated and rolled into a rail; care being taken, be it remarked, not to confound the top and the bottom of the pile, a guide is afforded however by the different colours of the two irons. The roughing rolls have five grooves, and the finishing rolls six.

The same method is pursued at Hörde. The furnaces for reheating the piles are provided with a blast; a centrifugal fan serves fourteen of them. The pressure does not exceed that of about $\frac{1}{4}$ inch of water.

Works of the Southern of Austria Railway at Grätz (Styria). — If joints in the top slabs are often tolerated or even systematically admitted, they are more frequently forbidden. Some German Engineers even find fault, from this point of view, with the usual condition of the piled cover; because it is then obtained from puddled bars, broken and piled in such a way, that welded joints are multiplied when it is important to avoid them. They therefore recommend, that the top slab should be taken direct from a single puddle ball of fine-grained iron. This ball should be shingled, not by the squeezer, but by the hammer, not only for the purpose of purifying the iron, but as a guarantee of its quality; the shock of a heavy hammer being a crucial test for puddle balls.

It is thus, that the rail manufacture is carried on at Grätz, the best iron o Styria and Carinthia being employed. The bars, placed immediately under the top slab are, obtained from old rails, broken and carefully assorted, having no defective weld, and approaching as much as possible to the nature of the top slab.

Hartwich Rail. The Horp works near Steele (Prussia) manufacture rails on the Hartwich system (193), for the part from Kempen to Kaldenkirchen, of the Venloo section of the Rhenish lines. The height has been, as has been said, reduced from $11\frac{1}{2}$ to $9\frac{1}{4}$ inches. The head is $2\frac{1}{4}$ inches wide, the flange 5 inches wide, and the web only $\frac{1}{2}$ inch thick. The weight per yard is about $88\frac{1}{4}$ lbs. As the rail is 24 ft. 9 inches long, its weight is nearly $6\frac{1}{2}$ cwt. Its author thinks, that the height might be still further diminished; and, if this dimension be retained, it is especially with a view to the stability of the points and crossings, which having their points of support, as has been seen (291), solely on the fixed rails necessitate a rather considerable height in the latter. The price, which is also that of the fish plates and joint plates, is very high, £11·2·0 per ton, but it is evidently provisional; in the manufacture of this type, there are no doubt causes for an increase in cost, but not sufficient to justify such a difference between its price and that of a rail of ordinary height. The pile is made of puddled bars, with top slab of piled iron obtained from phosphorous pig, and two bars of piled fibrous iron for the edges of the foot; it is heated, hammered, reheated, and then rolled. Perhaps, the second reheating may be dispensed with.

Mr Hartwich, now does away with the joint plate *p, p* (Pl. IX, figs 9 to 11); the solidity of the joints will also be more thoroughly ensured by increasing the length of the fish plates, from 17 to 24 inches, and the number of the bolts from eight to twelve.

A visit in May 1868 to the Venloo line enables the author to state, that the permanent way, laid on gravel, was excellent, and fully justified the predictions of its illustrious designer.

332. *England.* — The method of making rails varies considerably between one district and another. In the great centre of production which especially meets the export demand, that is in South Wales, the prevailing characteristics of this manufacture, when left untrammelled, be it understood, are : an inferior white pig, the use of the squeezer to purify the balls, and that of the blooming and cogging rolls, either reversing, or three-high, for welding up the piles; the top slabs, the whole breadth of the pile, are generally formed of piled iron chiefly for the purpose of giving the rail a good appearance. On account of the large section of the pile, two heats are given, the first before, and the second after the passage through the blooming rolls. This is the process at Ebbw Vale, Aberdare, and Dowlais. At the last named establishment, the mechanical puddler of Mr Menelaus is being tried; but we should exceed the scope of this work, if we were to stop to describe an appa-

ratus which has not yet come into general use. Figs 21 and 22, Pl. XXXII, represent the composition of two piles for the Vignoles rail at Ebbw Vale and at Dowlais.

The South Wales works accept, however, as do others, the conditions imposed by the consumer; for instance, those of French specifications. When, however, shingling the balls by the hammer is specified, the Railway Company must give way on that point. Thus the Southern of France Company was obliged to accept shingling by the squeezer.

The balls were formerly hammered at Ebbw Vale, for the manufacture of rails entirely from piled iron. They passed first into the three-high cogging rolls, bearing the name of Jeremiah Brown, their inventor. Freed from a portion of their cinder, they were piled, purified with great care, and made into plates 29 to 31 inches long, nearly 8 inches wide, and 2 $\frac{3}{8}$ inches thick. Four of these plates, with unsheared ends, composed the rail pile.

More than fifteen years ago 2,000 tons of double-headed rails, thus manufactured, were delivered to the East Indian Railway. The heads showed many cracks, which determined the company to return to cover slabs of piled iron. It would be interesting to know, how these rails stood; which were not perhaps of good appearance, but which must have been thoroughly homogeneous.

Since that time, all operations which are not absolutely indispensable have been discontinued; when only puddled iron is used, it is with the intention, not so much of securing homogeneity, as of a reduction in the cost, to which there is a tendency by all possible means, including an excessive proportion of forge cinder in the bath, and a very high temperature of blast. If there is anything surprising, it is not, that the rails thus obtained are often of inferior quality, but that they are not always bad. The counteracting advantages of this system are, however, on the one hand the large sectional area of the piles, and consequently the amount of working undergone by the iron, provided the piles be well filled up; and on the other the welding nature of the iron due to the phosphorus and the silicon.

The hammer now abandoned in Wales, where everything is made subservient to economy of manufacture, is on the contrary in constant use in Durham, Cleveland, and especially in Yorkshire; puddle balls, piles for cover slabs, rail piles, everything is hammered. With these elaborate precautions, united besides to grey pig of the best quality, and to careful puddling, the rails, even, if not to say especially, those of entirely pudded iron are necessarily good.

At the Crewe works of the London and North Western Railway Company, the old rails are used up, without being flattened. The pile for double headed

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rolled after thirty years of service, which gave bad results; they were defective in welding. It remains only to ascertain, if this defect, which Mr Holley attributes to an *excess of purity*, was not simply the consequence of a faulty method of manufacture. His opinion cannot in any case be taken generally. In his report, to which we shall return later on (355), as to the numerous fractures to rails noticed during the winter 1867-68 on the Erie Railway, Mr Riddle, the manager of that line, states, that the new rails obtained from Scranton broke in several places, sometimes after six months service, and that their fracture almost inevitably led to a running off the rails; while the rails re-rolled at Elmira broke but rarely, and only when previously much deteriorated. These, it is true, do not possess the hardness of the former.

334. *Fish plates and Spikes.* — In the rolling of fish plates there is nothing peculiar. For spikes an intermittent rolling mill is sometimes employed; that is to say, one in which the rolls are provided with recesses which create the swellings intended to form the heads.

§ III. — Tests.

In France rail tests are taken upon three heads : 1st resistance to deflection under a statical load; 2nd resistance to fracture by a statical load; 3rd resistance to impact.

335. 1st *Statical test.* — It would be uninteresting to reproduce here figures which, as they do not relate to the same sections of rails, cannot be directly compared. We will only mention the conditions imposed by the Eastern and the Northern Companies of France, because they relate to rails having very nearly the same section.

1st The rail, placed upon two supports 3 ft. 7 inches apart, having sustained for 5 minutes a load of 11 tons. 16 cwt. in the middle, should not show any permanent deflection after the removal of the load.

2nd Placed under the same conditions, it should support for 5 minutes without fracture a load of 29 tons. 10½ cwt.

The ratio admitted between the loads which must not cause, the one an appreciable alteration of elasticity, and the other rupture, varies but little between the different companies. However, the Lyons Railway Company fixes 12 tons 15 cwt for the former, and only 27 tons for the latter : which amounts

to saying, that it attaches especial importance to a great rigidity, and that it considers the property of resistance at fracture as sufficiently attested by a load of 27 tons.

336. 2nd *Dynamical tests.* — The French specifications stipulate, that the statical test N° 2 shall be continued until fracture ensues. The test by impact is applied on one of the two parts of the broken rails.

On the Northern, Eastern, and Orleans of France, the Western of Switzerland, and other railways, a portion of about 9 ft. (the rail being 19 ft. 6 ins. long) placed on supports 7 ft. 3 $\frac{1}{4}$ ins. apart, should stand without breaking the impact of a 6 cwt. ram, falling from a height of 6 ft. 6 $\frac{3}{4}$ ins.

The supports should be " of cast-iron, laid on an oak frame; which in turn rests on a foundation of masonry at least 3 ft. 3 ins. thick, on solid ground."

As we have seen (23), two companies, the Mediterranean and the Southern, make the height of fall dependent upon the temperature of the air; the second has adopted the same heights as the first named, but only as normal values, and it has fixed for each series of temperatures not only a minimum, but also a maximum of height.

	HEIGHT.		
	Minimum.	Maximum.	Normal.
Below 32° Fahr.	3 ft. 7 ins.	4 ft. 11 ins.	4 ft. 3 ins.
From 32° to 68°	4 ft. 3 ins.	5 ft. 7 ins.	4 ft. 11 ins.
Above 68°	4 ft. 11 ins.	6 ft. 3 ins.	5 ft. 7 ins.

Each rail tested undergoes successively the three tests, always commencing with the minimum height of fall. In order that the lot be accepted, it is necessary that the mean of the heights of fall which have caused fracture be at least equal to the normal height.

A compensation is thus established, within certain limits, between the weak and the strong rails; a circumstance which takes off from the severity of the condition, thus expressed in the other specifications.

" If more than a tenth part of the rails tested should not resist the shock, the
" whole delivery will be rejected. "

The Southern of France specification also prudently adds :

" The tests may be continued upon the rails which shall have resisted these shocks,
" but the results afforded by this continuation of test shall have no influence on the
" passing of the rails."

A too great extension of the limits of the compensation system would in fact end in allowing one fault to compensate for another, by admitting rails too rigid by means of those too flexible.

The advisability of the impact test is open to debate, at least as generally enforced. It is, no doubt, necessary to guard against the fracture of rails when laid down (*), but this should be done without sacrificing any of the essential conditions. The rails should not break, neither should they be too yielding; now to fix the intensity of the shock which a rail should resist, without also fixing the maximum of the corresponding deflection, so far from securing an essential property, is even to award a prize for a defect : flexibility. A rail which yields to a given impact might be in reality much better, than another which stands the shock without breaking, but at the same time bending more considerably.

It is not only for the sake of utilizing fibrous iron, but also with a view of resisting impact, that manufacturers make a point of introducing this class of iron into the foot, and railway companies admit it when they do not insist upon it.

The greater ability, as a rule, of this kind of iron to stand concussions without fracture is due to its considerable elongation in breaking, and consequently also to its deflection under a transverse blow. This elongation varies, even when only ordinary irons are under consideration, between very large limits. Thus, in submitting samples of plate iron to a tensile strain, Mr Hodgkinson met with figures comprised between $\frac{1}{160}$ and $\frac{1}{8}$; while the resistance to fracture varied only from 18 to 21 tons per square inch. Thus, there are some rails, with flanges formed of fibrous iron, very ductile, the complete fracture of which it is difficult to effect by concussive blows. The head may soon break, but the foot is drawn out, and continues to resist the action of the blows.

(*) The question is not, be it understood, one of fractures resulting from an accident, a running off the line, for instance; as to those which are due to a slight settlement, to those imperfections of the permanent way, which it is not always possible to avoid; they are extremely rare in the present day, thanks to the increase of the rail section.

Fig. 25, Pl. XXXII, represents a curious example of the fracture of a rail too weak for the rolling stock. This double-headed rail, about 51 lbs to the yard (a type already noticed in N° 23), was laid down 15 years ago on the Strasburg and Bâle Railway; the replacement of these rails by those of Vignoles section was put off in consequence of the delay in delivery on the part of the manufacturers. Only 14 ft. 9 ins. long, it was broken in fourteen pieces. The iron was sound, and of medium grain.

The fracture took place on the passage of a goods train. The last seventeen wagons were thrown off the rail; it is probable, that some of the numerous fractures to the rail were due to the wagons leaving the rails caused by the first fracture. That all these fractures should have occurred together is, indeed, a very unlikely circumstance.

One must not however generalize too much on this property of fibrous iron; and especially one must not exaggerate its effect on the life of rails.

We have already remarked (22), that deflection under a statical load, corresponding to an appreciable permanent deflection, varies but slightly in different kinds of iron; and that if the deflection of fracture varies considerably, these variations are at least in certain cases, independent of the texture of the iron. On the other hand, so long as there be not permanent alteration of form, deflection under the load is independent of the structure, since the coefficient of elasticity itself does not depend upon it.

The fact of the rail being composed partially, or even wholly, of fibrous iron makes no change, compared with that of its being composed entirely of granular iron, either in the amplitude of the deflection under a load inferior to the limit of elasticity, or as to the point where the alteration of the latter begins. The introduction of fibrous iron, therefore, has influence only upon two elements : 1st the hardness, indispensable in the head, and which ought to exclude from it this sort of iron; 2nd the deflections under loads capable of impairing the elasticity, and their limit, that is to say, the deflection at the instant of fracture. And again we repeat, the table in N° 22 shows that this influence is not absolute.

337. It is to be regretted, that Herr Weishaupt should have neglected to make observations on resistance to impact, thus leaving a gap in his interesting series of experiments (19). It is possible, however, to supply these in part. The product of a statical load by the corresponding deflection, expresses, with a tolerably near approximation, double the intensity; that is to say double the force of the blow which would develop in the solid the same *maximum* molecular effects.

P being the weight of the falling body, H its height of fall corresponding to fracture, φ the deflection, at any instant whatever, of the bar supposed to be of rectangular section, π the statical load which would produce this deflection; $\pi d\varphi$ is the elementary work of the molecular elasticity corresponding to an increase infinitely small $d\varphi$ of the deflection. f being the final deflection due to the blow, that is to say the deflection of rupture, the energy

$$\int_0^f \pi d\varphi$$

ought, not taking into account the *vis viva* acquired by the prism, and the deformations on the contact of the two bodies, to be equal to the force PH of the blow.

We have therefore

$$\int_0^f \pi d\varphi = \mathrm{PH}$$

but

$$\pi = \frac{48\,\mathrm{EI}\,\varphi}{a^3}.$$

substituting and integrating,

$$\frac{24\,\mathrm{EI} f^2}{a^3} = \mathrm{PH}. \qquad (1)$$

P_1 being the statical load at fracture, we have

$$f = \frac{1}{48}\,\frac{P_1 a^3}{\mathrm{EI}}.$$

substituting this value in (1) for one of the factors f, it becomes

$$\mathrm{PH} = \frac{1}{2} P_1 f. \qquad (2)$$

This relation supposes that the prism passes, under the action of the blow, through the same successive forms as under increasing stationary loads; this hypothesis is, however, incorrect, and is the more removed from the truth the greater the speed, with equal intensity, the falling body possesses, and consequently has a less considerable bulk. Thus in an extreme case, when the question is one of projectiles, the effects are quite different; they concentrate themselves entirely on the region which receives the shock; there is local penetration without general deflection.

The preceding result is in a measure applicable to the usual conditions of experiments by impact made on rails, the bulk of the piece to be tested being far from negligeable with reference to that of the ram. But the application is more admissible, when the question is one of deducing from statical tests the resistance to impact of rails in actual use; the height of the striking body whatever it be, in that case being very slight.

Besides, the relation (2) is also founded on another hypothesis, equally incorrect in principle; upon the persistence, up to the point of fracture, of the proportion between the strains of tension and of compression, and the corresponding variations of length. This hypothesis would be completely inadmissible in the case of bodies which, like cast iron for instance, offer very unequal resistance to fracture by tension and by compression; but it is much less incorrect in the case of bodies in which the equality of the two

elementary resistances is persistent almost until fracture ensues, so that the neutral axis becomes displaced to a very slight degree, as the loads increase; and definitively that the state of equilibrium of the solid is still represented with a tolerably near approximation, almost up to fracture, by the formulæ established only for slight strains of molecular elasticity. The well known experiments made at Portsmouth, prove, in fact, that a sufficient approximation is thus obtained in practice.

Now if we group together, taken from the first table of N° 20, the experiments made on rails having almost the same weight, and for which, all the data as well as the texture of the iron have been given, we shall form a table as follows:

NUMBERS of order in table of n° 20.	NAME of the works or of the manufacturer.	WEIGHT of the rail per yard.	TEXTURE OF THE IRON.	PRODUCTS of the statical breaking load by the corresponding deflection, or double the resistance.
		lbs.		Foot-pounds.
9	Kœnigshütte....	67 ½	Fine steely grain, with the exception of the flange being a little fibrous........	30,711
5	Jacobi.......	65 ½	Fine-grained, fibrous in the flange...........	28,452
8	Eschwelleraue. .	66	Fibrous, with the exception of the head being slightly granular............	22,932
6	Eschwelleraue. .	65 ½	Fibrous, with the exception of the head being slightly granular............	20,623
10	Laura.......	65 ¾	Fine-grained, very fine at the edges and in the flanges...	19,425
7	Kœnigshütte....	65 ¾	Coarse-grained in the interior with finer grain at the edge, and slightly fibrous in the flange............	19,180

Rail N° 6 has, therefore, although consisting almost entirely of fibrous iron, a resistance much less than that of rail N° 9; composed almost entirely of granular iron, and of but slightly greater weight. This same rail N° 6 has only a slight advantage, as regards this resistance, over rails 10 and 7, of the same weight and both consisting of granular iron. It is clear, moreover, that the effect of differences of texture may very easily, as a general rule, be concealed by differences in the quality of the irons; but this is not the case here. It being a question of medium quality irons; capable of being compared, if not actually identical, as regards their quality.

If the influence of texture on resistance to fracture by impact is far

from being constant, it is nevertheless incontestable that it is sometimes manifested in the clearest manner. Thus, when not very long ago the Eastern of France Railway Company had double-headed and Vignoles rails supplied at the same time, the inferiority of the resistance of the former was so marked that the height of fall of the 6 cwt. ram, fixed as it still is, at 6 ft. 6 ins. for the Vignoles rails, had to be reduced to 4 ft. 11 ins, for the double-headed rail; and even then, while the former easily stood the test, the company were often obliged, in order to avoid the rejection of rails they knew to be good, to reduce to 4 ft. 9 ins. and even, to 4 ft. 7 ins., the height of the fall for the latter class of rails. The weight being the same, the difference could only be explained by the nature of the flange of the Vignoles rail made of fibrous iron; while this class of iron only entered to a small extent (the web), into the composition of the double-headed rail.

There is, however, no occasion to take notice here of slight differences of section, provided that the sectional area be the same; the resistance to impact only depends, in fact (always with the same degree of approximation), on the mass, as may be at once ascertained in the case of a prism of rectangular section.

Let us, in fact, again take the approximate relation

$$PH = \frac{1}{2} P_1 f \qquad (2)$$

and the values:

$$f = \frac{1}{48} \frac{P_1 a^3}{EI}, \quad P_1 = \frac{4 I R}{Va};$$

substituting the last expression in the former equation,

$$f = \frac{1}{12} \frac{Ra^2}{EV} \qquad (3)$$

substituting in (2) these values of P_1 and of f,

$$PH = \frac{1}{6} \frac{R^2}{E} \frac{Ia}{V^2},$$

b and c being the sides of the rectangular section, we have:

$$V = \frac{c}{2} I = \frac{1}{2} bc^2,$$

whence,

$$PH = \frac{1}{18} \frac{R^2}{E} abc = kV,$$

V being the volume, and k a number.

The conclusions to be drawn from this investigation are: 1st that the mere fact of fibrous texture is not of itself a sure guarantee of a greater resistance to impact (let us remind our readers of 319, note; that this texture is often partially due to the more intense action of the rolls on the foot of the Vignoles rail); 2nd that this resistance may be approximately deduced from the observations of fractures and deflections under statical loads. This method even possesses the same, if not a greater, degree of exactness as does direct experiment; and it especially possesses the advantage of rendering comparisons more justifiable. As the appliances made use of in impact tests possess differences which exercise a great influence on the results, and which are in no way removed by the vague terms in which the specifications describe the erection of these appliances.

However that may be, if impact tests be admitted, it is difficult to allow that the conditions are wisely framed by the specifications. By abstaining from placing a limit to the deflection under load in the statical test, and by imposing only, in the dynamical test, the condition of resisting a blow of fixed intensity, manufacturers are encouraged to produce soft and flexible rails. This tendency is doubtless counteracted, to a certain extent, by the stipulation that there shall be a granular texture in the head; but the conditions should be in accordance with one another, and be all directed to a really useful end. The condition of resisting a given shock would only be effective, if a limitation were also imposed, either on the deflection under impact, or, better still, on the permanent set after impact.

§ IV. — Case-hardening of the rolling surface. — Rails with Bessemer steel or with puddled steel heads.

338. It was primarily in the case of points and crossings in the permanent way, that the rapid destruction of iron led to the substitution of a stronger material (275 and folg.); but the same necessity was not long in also making itself felt in the remainder of the running rails. In fact, the destruction of the rails attained excessive proportions at certain points on lines having considerable traffic, especially at stations and their approaches, and on gradients.

The special causes of the destruction of rails at stations are: the increased passage over them on account of shunting; the state of the rails, generally greasy, a state which often leads to slipping, one of the most injurious con-

ditions that can happen to rails; and lastly, the frequent action of the brakes, also very injurious, when it is so intense as to lock the wheels.

As to a gradient, it does not affect the two lines of way in the same manner. With a rising gradient, the conditions are aggravated : 1st by the increase of the tangential strain of the driving wheels; 2nd by more frequent slipping; 3rd often either by the rails being more run over through the use of relief engines, or from shunting backwards and forwards; or else from the use of special locomotives, more powerful and therefore heavier.

On a falling gradient, besides being subjected like the rising one, to this third influence, the most active cause of destruction is the action of the brakes, especially if an important station be situated at the foot of the incline; as all the trains have to slacken speed almost entirely on the incline itself, and the slipping of the wheels then becomes frequent. Such is the case with the Etampes incline for instance. The destruction of the rails is, however, much more rapid on the falling than on the rising gradient.

These special causes of destruction on gradients have, in the first place, been met by an increased weight in the rail. But this means is not more efficacious on a gradient than elsewhere; if the rails simply wore away, their life might be prolonged by opposing to the causes of wear a reserve of stored up metal, as it were. But, inasmuch as, on a gradient as well as on the level, the deterioration of the rails arises from splintering, from deformation, and not from wear, and as they generally have to be taken up without having experienced any appreciable loss of weight, it is not in an increase of the total sectional area, nor in a greater concentration of metal in the head, that the remedy must be sought, but in the very nature of their substance, in its hardness and tenacity.

The inadequacy of iron is now acknowledged on most of the large lines. In Germany, at the enquiry of 1865, two Boards of directors only, those of the Eastern of Saxony and Thuringian Railways, expressed themselves content with iron rails, provided they were well made. It is, however, a question of configuration of district, and of traffic.

It was only natural with rails to seek to harden the rolling surface, as had been done for a long time past in the case of various parts of locomotives.

The Orleans Company caused experiments to be made in this direction, some time ago at the Terrenoire and at the Alais works.

A furnace was used similar to those for the cementation of steel. Two chests, 23 feet long, held each 36 rails, piled up in such a way as only to leave spaces between the heads; which spaces were filled in with the cementing

powder. The latter was composed of charcoal in pieces, mixed with cement remaining from previous use, and a little limestone and carbonate of soda. The influence of these salts on the result appeared however to be null. The operation lasted about 72 hours. The duration was, however, determined by proof bars. A skin from an eighth to a quarter of an inch thick was thus formed on the heads, very hard and having a steel-like grain. Vignoles rails thus treated at Alais were laid down at the approaches to several stations on the line between Limoges and Périgueux, and the result was very satisfactory.

The Orleans Company paid for the rails, case-hardened at Terrenoire and at Alais, at the rate of £1.12.0 to £2 per ton over the regular price.

The case-hardening of double-headed rails raises an indirect but serious objection. One head only ought to be case-hardened, as the operation renders the iron brittle when subjected to tension. Turning the rail (30) ought, therefore, to be forbidden, which diminishes the advantage of hardening the single wearing surface; but the greatest drawback is the difficulty of getting this attended to, and of preventing the rails from being placed upside down, either when first laid or during the maintenance. According to M. Sévène, the engineer-in-chief of the permanent way on the Orleans line, this reason should suffice to reject the application of case-hardening to double-headed rails.

Regarded in this light, case-hardening itself should be condemned, independently of all chance of mistake in laying the rail, if the generally admitted theory be true as to the ends of each rail-span being rigidly fixed. With this hypothesis, it is the upper head which is in tension at the sections of greatest strain, over the points of support (68). But similarity of loading on adjoining spans, a condition which alone would realize this fixity, seldom happens (69): and in fact, partial fractures, when they occur, nearly, if not indeed always, are met with in the lower portion of the rail which is in tension.

Strains of tension are also developed, doubtless, in the upper head. A solid body, such as a rail or an indefinite line of rails rendered transversely continuous by fishing, laid on several supports in a straight line, and bending under moving loads, necessarily presents points of contrary flexure; that is to say, points at which, the same longitudinal fibre passes from tension to compression, and *vice versâ*. But, as each span is almost always in an intermediate condition between having its ends free and having them rigidly fixed, the tensile strain does not attain, in the extreme upper fibres, so high a limit as in the farthest lower ones.

239. Case-hardening has been very largely made use of by the Southern of Austria, and by the Central of Italy on the line from Bologna to Florence.

The whole of the passage over the Apennines, on the section from Poretta to Pistoïa, having for a length of nearly 25 miles an almost continuous gradient of 1 in 40 with curves of 15 chains radius, has been laid with steel-headed rails; the rail is that, already mentioned (31,95), used on the whole system, and weighing 72 lbs to the yard (Pl. XXXII, figs 1 to 8).

The rails of this section, made at Ruhrort (Phœnix works), were there case-hardened by the Dodd process.

The nature of the iron and the composition of the piles are far from being without influence on the success of the operation. After several attempts, it has been found at the Phœnix works that the most suitable is fibrous, or strong iron, which stands heat better than any other.

The pile was therefore composed entirely of fibrous iron. Fig. 8, Pl. XXXII, shows the mode of its arrangement. It was raised to a white heat, welded, and drawn out 13 inches long under a 3 ton ram, falling 4 ft., then reheated and rolled.

The process is marked by the special construction of the furnaces, and by the methods of charging and discharging, which take place without any demolition, and without waiting for cooling. The furnaces form a group of four. Each of them consists (figs 1 to 6) of a vaulted space, O,O, containing two case-hardening chambers, C,C, of two chimneys, *l*,*l*, and of a fire-grate, F, situate in the middle; the fire runs the whole length and is fed from the two ends. The two chambers, C,C, are formed of large fire-bricks; those forming the sides of the chamber being as long as it is high, while the floor ones run its entire width. The segmental arch, *v*′, which covers in the kiln, is made of fire-bricks of special form. These kilns rest on 21 fire-brick supports, *s*,*s*,*s* (fig. 3), leaving between them spaces forming horizontal flues, *h*,*h*, for the circulation of the flame; which also traverses the vertical flues, *b*,*b*,*b* (figs 1 and 5), entirely surrounding the chambers, and makes its exit by the side openings, *f*,*f*, and the flues, *e*,*e*, into the chimneys *l*,*l*, the draught of which is regulated by means of dampers *r*,*r*.

The vaulted roof of the furnace is of fire-brick, covered on the outside with a row of fire-bricks, and in addition protected against cooling by a bed of sand *k*,*k* (fig. 1). The length of the furnace exceeds by 3 ft. 3 ins., that of the rails to be case-hardened; the excess of half that length at each end, between the rails and the door, admits of a small wall, *m* (fig. 3), being built; the space between this wall and the door, P, is filled with sand, *k*′ (fig. 3), to guard against loss of heat.

Each chamber takes 28 rails, arranged in four horizontal rows of seven rails each (figs 1 and 7). The lowest row has the heads uppermost, and is

set upon a bed of refractory sand. The spaces are filled with the same sand up to the commencement of the rolling surfaces of the rail. Next comes a layer of cement, formed of hardwood charcoal (oak or beech), shovel-mixed with one-twentieth part of carbonate of soda. This layer, about 2 ins. thick, is spread as evenly as possible by means of iron rakes. It receives the second row of rails laid head downwards, and the spaces intervening are filled in with sand. The third row is laid in immediate contact with the second, heads uppermost; the spaces are filled in with sand, and the heads are covered with a layer of cement, which is common to the third and to the fourth row, laid heads downward.

The charging of the rails is accomplished by means of rollers, capable of being adjusted to a convenient height by means of a toothed-rack support. The rollers being arranged at the two ends of the furnace, four men bring the rail, place one of its ends on the roller, and push it forward until its middle reaches the roller; a man receives the forward end on a lever provided with rollers, guides the rail, while a single man pushes it from behind, places it in its row and sets it either on its foot or on its head.

When the charging is finished, the small walls, *m*, at the ends of the chambers, are built up; test pieces, that is to say small bars of the same iron as the rails, being inserted at even distances; the doors, P, are closed, and the heating is conducted regularly by carefully spreading the coal over the whole length of the grate-bars, by means of a long hooked fork.

The operation takes ninety-six hours, including charging and discharging the furnace, for a case-hardening to the depth of $\frac{1}{4}$ inch. The maximum temperature, which must be attained at the end of thirty-six hours, is that which corresponds to orange red. The sight holes, and the spaces left by the test bars as they are successively withdrawn, permit of what passes within the furnace being watched.

When the test bar shows that the desired depth of case-hardening is reached, the small walls, *m*, of the chambers are pulled down; planks are placed across the pit of the furnace, and the operation of discharging commences. A long iron rod, fixed to a chain wound up by a winch, seizes each rail with its hooked end by engaging it in one of the fish-bolt holes, and then withdraws it from the furnace, by making it pass over a sort of horizontal ladder, each rung of which is a roller, and fixed on trestles of variable height. The rails are straightened by a beam press, when sufficiently cool to be handled. The sand and ashes withdrawn from the chambers after discharging are taken back to the shed where the mixtures are prepared, and sifted to extract the fine particles of unburnt charcoal, which are used over again in the case-hardening

process. The sifted ashes and sand are also used for filling the spaces between the rails, and for covering in the whole. The following are, according to the Engineer, Sig^r Montegazzo, the approximate details of the cost price of the operation per ton of rails, and the conditions of delivery.

1st. — *Price.*

	s · d
Charcoal: 3qrs. 4lbs. at 4s. 1d. per cwt.	3 · 2
Grinding.	· 2¼
Carbonate of soda 4½ lbs. at 14s. 3d. per cwt.	7
Coal: 16 cwt. 2 qrs. 4 lbs. at 9s. 9d. a ton.	8 · 0
Stokers' wages.	3 · 1
Straightening.	3½
	15 · 4
General expenses and interest on capital expended on furnaces.	2 · 1
Total.	17 · 5

2nd. — *Conditions of delivery.*

1st. Placed on two supports 3 inches wide and 3 ft. 7 ins. from centre to centre, the rail must sustain for 5 minutes a load of 11 tons. 16 cwt. without permanent set;

2nd. It must sustain without fracture, for five minutes, a load of 24 tons. 12 cwt. The load will then be increased until fracture takes place;

3rd. Each of the two pieces, placed in their normal position on supports 6 ft. 6 ins. apart, must sustain without fracture the blow of a 8 cwt. ram falling through 5 ft. 7 ins. on to the middle of the bar. In this test the supports are to be of cast iron, and to rest on an oak framing laid on a foundation of masonry at least 3 ft. 3 ins. thick;

If one of the bars should not stand this test, the trial shall be continued on a large number of bars; and if more than $\frac{1}{10}$ of the bars tested should not stand the test, the whole of the rails from which the trial bars were taken shall be rejected;

4th. The length of the warranty is 5 years.

The result would appear, however, to have been satisfactory.

" M. Montegazzo," says M. Berrens, the predecessor of that engineer in the permanent way department, in an autograph note bearing date June 1876, " wrote me " lately that, notwithstanding the numerous curves of small radius, the frequent use " of brakes on descending gradients, and the great lateral pressure of the immense " eight-wheeled engines on the Beugniot system, there is no apparent deteriora- " tion after three years service; and that over the whole line, he only had to " change three rails that had laminated at one end. "

According to the same engineer, 32 case-hardened rails laid down at the Ruhrort station showed only a very slight wear at the end of twenty months; while rails obtained from the same works, but not case-hardened, had to be changed at this spot every four months.

340. *Durometer.* — The hardness of the heads is an essential point to ascertain. In order to estimate their intensity with precision, by reducing them to a common standard, an appliance is sometimes used which seems to have been employed for the first time by M. Berrens on the Lombardy railways. The principle consists in comparing the distances, which a drill with a double cutting edge of $\frac{3}{8}$ inch diameter, loaded with a constant weight (22 lbs), penetrates after the same number of revolutions (50) into the skin of the rail to be tried, and into a blade of cast-and-rolled steel which is taken as the standard. The *durometer* constructed by M. Froment in 1859 had one defect: the penetration diminished with the depth, without its being possible to attribute this anomaly to the blunting of the cutting edges of the drill. M. Berrens found out, that it was due to the action of the tool on the detached filings; it ceased, in fact, when the precaution was taken of isolating beforehand, by means of a preparatory tool, the small cylinder, $\frac{3}{8}$ inch in diameter, to be attacked by the drill. The instrument registers the deepening of the holes to the 0.0004 of an inch. The hardness is measured by the ratio of the depth of holes in the standard, and in the rail. This ratio, which is 0.55 to 0.6 for French and Belgian rails, is as high as *par* for the rails case hardened at the Phœnix Works.

341. *Rails with Bessemer steel head.* — The Dodd process, properly applied, is effective; but, if it increase the durability of the rails which are welded up, if it improve, and doubtless it does so to a great extent, rails already good, it is of no value for rails of medium quality, and especially for those imperfectly welded up; it would only aggravate their defect.

Instead of simply hardening the wearing surface by annealing it, the same plan which has been in use from time immemorial may be adopted for rails, the conjunction of iron and steel, the latter forming the portion on which the destructive forces immediately act. But, that which is perfectly feasible with pieces of moderate size, tools for instance, where the body is of iron and the cutting edge of steel, is by no means practicable in the case of rails. The subsequent application of layers of steel constitutes a costly process, tried, and not without some measure of success for special appliances, such as points and crossings, but which is evidently not capable of being extended to ordinary rails. For the latter, the association of iron and steel is only possible on condition of a single operation, as with iron alone (*).

(*) The application of layers, but only partial and of iron, and consequently more easy to weld, has for a long time been in use at the Darmstadt works. It is towards their ends that the rails are most frequently defective; instead of rejecting all those that are defective at the ends but sound elsewhere,

M. Verdié had succeeded, by running cast-steel on iron, in obtaining if not a weld properly so called, at least a connection, with a sufficiently good joint. But in presence of the lowering in price of steel proper, and the introduction of Bessemer metal, there was no longer any need for this process, and its inventor has abandoned it.

As far as rails are concerned, the tendency now-a-days is much more towards homogeneity, — iron for lines but little run over, Bessemer metal for those with much traffic or with sharp gradients, — than the association of iron and steel.

The question of the mixed rail has however, as a transitional measure, a real present importance for certain Railway C[ies]; who, convinced of the inadequacy of iron, and adopting as a principle the rail entirely of steel, but being in a bad position for turning to account, on tolerable conditions, their rejected iron rails, have to use them up themselves, though at the same time improving the conditions of resistance of their wearing surface. Whence arises the *steel-headed* rail, for which the Bessemer metal affords a substance doubly valuable, on the one hand on account of its moderate price, and on the other because a continuous process, that is to say rolling, suffices to effect between it and the iron a sufficient union.

342. It is on the Southern of Austria, that this method of using Bessemer steel has been most studied and applied at the present day, and on the largest scale. Up to the year 1864, experiments only, under the direction of the skilful manager of the Grätz shops, M[r] Hall, were made; but since the year 1865 the production of steel-headed rails has amounted to 6,000 tons.

The top slab of steel with projecting edges (323), is nearly $1\frac{3}{4}$ inches thick in the middle, and 3 inches at the edges; the steel constitutes more than $\frac{1}{4}$ of the pile, which is $10\frac{1}{4}$ ins. high. The bottom slab is formed of two rail ends flattened between the rolls.

The result of various experiments, — fracture under the hammer, immersion in water of the bars raised to a red heat, and concussions having a tendency to separate the layers, — had inspired much confidence in the union between the head and the web. The manner in which the rails behaved at those portions of the system, where they were most tried, seemed so completely to justify this confidence, as to allow the steel-headed rail to be applied to the crossing of the

pieces are welded on to the heads. As we have already said (33), expedients of this kind may be justified; but only, when the distance from works at which old rails may be treated is such, as to cause their length of service to be prolonged by all possible means.

Brenner Pass. According to Mr Hall, defects of weld were no more to be feared in these mixed rails than in those with top slab of piled iron; inasmuch as the steel employed might stand without danger a temperature very nearly equal to that which is suitable for the welding up of the puddle-bar, placed immediately underneath the top slab.

A commission composed of very competent engineers was charged in 1867 by the directors of the Southern of Austria Railway, to study the different questions connected with the use of steel in rails.

While acknowledging, that the rail entirely of steel is preferable in principle, it gave as its opinion, that the manufacture of the steel-headed rail, as carried out at Grätz, should be retained as being the best method of using up old iron rails. If this combination be abandoned, it would be necessary to make rails, some entirely of steel, and the rest entirely of iron; and the committee, sharing Mr Hall's opinion, consider that the latter, requiring a top slab of granular piled iron, are not appreciably nearer homogeneity, and consequently do not offer greater guarantees of a good weld than do rails, the top slab of which is of Bessemer metal.

The Hörde works (Prussia) also make mixed rails, with the head of Bessemer steel and the remainder of fibrous iron; their price is lower by from 14 to 21 per cent than that of rails entirely of steel.

The George-Marie works, at Osnabrücke, also associate Bessemer steel and fibrous iron; with these two dissimilar metals the joint is made in the web.

343. In England, the principal iron works in South Wales, those of Dowlais, also commenced this manufacture, but did not continue it, as the process appeared difficult, and the advantage slight; or at least it was but little appreciated by the greater number of English railway engineers, their predilection for symmetry extending, in fact, to the nature of the rail as well as to its form.

However, at the Crewe works of the London and North Western Railway, and at those of Messrs S. Fox and Co, a tolerably large quantity of mixed rails have been turned out. That Railway Company has laid down several thousand tons; and up to the present time but very few defective welds have been discovered.

344. Mr Kirkaldy has tested to fracture double headed-rails, with the steel head above, and also underneath.

The breaking load in the latter position exceeded by almost 10 per cent (25 tons 10 cwt. 3 qrs., as against of 23 tons 6 cwt. 2 qrs.), that which corresponded to the former position. Here occurs therefore the inverse of

what takes place with case-hardened iron; which is quite natural, the steel being more resisting than the iron, while case-hardening renders the iron brittle when in tension.

It is however, in both positions, under tension that rupture occurs; in the former, the iron tears while the steel remains intact; in the second it is the steel which gives way, and the iron resists. Whence it follows, that if it be good to make the upper head of steel, it would also be advisable, as regards transverse strength, if the same were done with the lower one; especially where this is of smaller sectional area, as in the rail of the Pistoïa line. But so near would this approach to a rail entirely of steel, that there would be but little advantage in stopping short of the latter.

345. *Rails with puddled-steel head.* — The manufacture of puddled steel dates back, in Germany, for a considerable period (*); and its use seemed calculated to assume a tolerably large development, when Bessemer metal supplanted it in a large number of its actual and intended applications. The capital objection against puddled-steel is, as is well known, its want of homogeneity.

The Cologne and Minden, and the Berg and Mark Railways many years ago made use of rails with puddled-steel heads, the former only by way of trial, but with success; rails of this kind, laid at the Hamm station were after more than ten years still in good condition. The latter line has more than 10,000 tons of these rails laid down. According to the general practice in Germany, the rail piles are hammered, as well as the balls, reheated, and rolled. The remainder of the pile is sometimes of granular iron, and sometimes of fibrous iron. In the second case, the joint of the steel with the iron ought to be in the web.

A number of rails, some with puddled steel head, the others entirely of steel, were laid in 1861 on the line between Magdeburg and Wittenberg; the separation of the head was of rather frequent occurrence in the former. Rails with puddled steel heads, and the web and foot of fibrous iron, are also manufactured for the Austrian State Railway, at the Reschitza works (Banat).

The production of these mixed rails has also been much studied at the Phœnix. Sometimes the head alone, sometimes the head and web are formed of steel; the remainder is of strong iron, uniform in texture.

Fig. 23, Pl. XXXII, represents a pile for a steel-headed Vignoles rail, where

(*) According to Herr Maurer "*Die Formen der Walzkunst*", Stuttgart, 1865, this manufacture was already in activity in 1835 in the works of Carinthia; in 1862 thirty-one works had adopted it in Prussia.

all the layers not sectioned are of puddle bar or old rails re-rolled; the pile is heated, hammered, reheated, and rolled.

The show-case of this large establishment, at the Paris Exhibition of 1867, contained a series of these mixed rails, with varying proportions of steel, which would justly have formerly attracted attention; now however it is only of minor interest. In presence of the advantages, every day better appreciated, of complete homogeneity, of the absence of all weld, the only absolute guarantee against defects of this nature, it appears as if a process which yields a cast product ought to bear off the palm from all others; just as a radical remedy surpasses simple palliatives.

§ V. — Rails entirely of steel.

The increase of traffic, the lowering of the price of steel, or rather of the intermediate products possessing some of its properties, the conviction, every day more strongly confirmed, of the advantages which they afford, tend to induce companies henceforth to use them to a considerable extent on their permanent way; and the epoch may be looked forward to when iron will be relegated to lines of inconsiderable traffic and of easy gradients, on which its durability will be sufficiently great to keep the annual expense slightly below what it would be if steel were used.

346. 1st. *Puddled steel.* — This has not been brought into general use in France except for rails for special purposes. Bessemer metal has superseded it, with few exceptions (282). The latter has indeed the advantage of economy, and it is difficult to withhold from it that of quality also; as a cast homogeneous substance offers a greater guarantee of soundness than one, obtained by welding between the rolls a pile, the composition of which is with difficulty kept constant; which is especially the case with puddled steel.

In Austria, on the Northern line, puddled steel rails are in much favour. In the year 1859 the Northern Company commenced the use of puddled steel for special forms of rails, and in 1861 it laid down puddled steel rails at several stations of its system; and also on the open line of the Weisskirchen and Pohl section, where, on account of the gradients, iron rails lasted only a short time. At the expiration of the three years warranty, only 0.41 per cent of the steel rails had to be taken up. The rail section is that of the Austrian State Railway (Pl. V, fig. 33).

As a set off to this result, and to one equally favourable obtained on the Lower

Silesia Railway, it must be mentioned that out of a lot of 2,000 rails laid down on the State Railway of Bavaria, a considerable proportion were worn out at the end of three years.

This is not surprising, as it is difficult to obtain puddled steel of a constantly uniform quality. The Northern of Austria Railway must have been highly favoured (as is moreover explained by its unique position), to be able still to lay down at the present time, and this is the only instance of the kind, puddled steel on the same line as Bessemer metal, and use them concurrently. Uniformity in the degree of refining, and homogeneity in the puddled product are generally very difficult to obtain in a large quantity.

347. 2nd. *Cast steel.* — Refined cast metal, producing a rail drawn from a single ingot, presents, in the case of solid bodies placed in the complex conditions to which rails are subjected, guarantees of homogeneity which a pile, even welded up under the hammer before rolling, can never offer in the same degree. Neither lamination nor splintering is to be feared; and as to the proper degree of hardness, this quality is obtained more and more easily, and with the necessary constancy. As steel can only be heated with great care (to cherry redness), there might be some fear lest it should be difficult to get sound edges by rolling, especially in the flange of the Vignoles rail; but experience proves that it is easy to reconcile all the following conditions, moderate temperature, sound edges in the foot, and sufficient hardness in the head.

The success of crucible cast steel was undoubted; but its high price necessarily restricted its use to rails for special purposes. Thus the Northern of France Railway, in 1863, ordered from Sheffield (John Brown and C°) rails for which it paid at the rate of £26 a ton; a price which, however, has since fallen, thanks to the competition of the Bessemer metal, but not nearly enough to enable it to maintain its ground.

The greatest producer of steel on the continent, Herr Krupp, of Essen, supplies to German railways rails, which were at first sold as being of crucible cast steel, but which he now acknowledges are obtained from the converter (*). Another large establishment, which also enjoys a well-deserved reputation, that of Bochum, also claims for all its products (278), that they are made of crucible steel; excepting rails which are acknowledged not to proceed from the crucible, but from the Bessemer converter.

One of the effects of the legal restrictions upon inventions in Prussia, where

(*) When visiting, in May 1868, the works of Herr Krupp, the author was not admitted to the Bessemer department, some modifications, he was told, had been made in the process.

patents are only obtained with great difficulty, is to maintain a disposition towards mystery as regards manufacturing processes; a rather antiquated idea, as no one imagines, in connection with iron manufacture at least, that actual secrets can remain for a long time confined to any individual works.

However that may be, Bessemer steel has made great strides during the last few years (353); and its price has fallen with such uniform rapidity, that crucible cast steel (a term which includes some substances differing very much from each other) cannot compete with it as far as ordinary rails are concerned.

348. The Paris, Lyons and Mediterranean Company treated, in 1867, with the Terrenoire and Bességes Company at the rate of £12·12s. the ton; a figure which is far from being double the price, which had already got very low, of iron rails (*).

The Southern of France Company also dealt in 1867 with the same works for 3,000 tons at the rate of £13·13s·7d., delivered at Cette; which is equivalent to £12·14s. at the works. It will be readily understood, that at these prices the Lyons Company did not hesitate to adopt the Bessemer rail on the main line between Paris and Marseilles, and for sections with sharp gradients on the rest of its system. An order for 20,000 tons of Bessemer rails immediately followed this resolution, and it has since been doubled.

This example was not long in being followed, to a certain extent, by companies which up to the present time have only used steel for special appliances, such as points and crossings. After having declared, that "almost all "rails ought to be renewed every fourteen or fifteen years at the outside; "and that, on lines with heavy traffic, like those of Versailles, Auteuil, and "Havre, wear takes place with great rapidity", the Western of France acknowledged, that "it would probably soon be obliged to substitute steel "rails for iron ones" (**).

"What has prevented us hitherto," it adds, "from adopting steel rails generally "is the high price at which they are sold. But we hope that, thanks to the efforts "of manufacturers, this price will soon become lower, so as to be within the reach "of railway companies."

It must, however, be acknowledged, that the price of Bessemer metal has

(*) This low price might have been caused, to a certain extent, by the fact of advances being made to the works; a fresh contract was, however, made at the same rate.

(**) Report to the general meeting, 30 March 1868.

uniformly decreased, in France at least, in a perfectly unexpected manner; if the hope expressed by the Western Company becomes realized, the cause will perhaps be due to processes in which the choice of pig is less limited, but the success of which is as yet only assumed (265).

The Northern of France has adopted the Bessemer rail for the section between Paris and Creil by Chantilly; the Orleans Company, for the portions with very sharp gradients on its main system; and Southern of France, for the Montréjean incline, etc.

The Paris, Lyons and Mediterranean Company has, at the same time, completely coincided in the arguments set forth in Chapter II of this work. It is, in fact, the Vignoles rail, which it has adopted for application on a large scale.

349. *Weight of the steel rail.* — It is natural to enquire whether, in adopting steel, it is not possible to compensate, at least partially, for the difference of price by a reduction in weight, without sacrificing the advantages due to the use of steel.

The Northern of Austria, after having first applied puddled steel to their ordinary rail-section, compared the strength :

1st. Of an iron rail of ordinary section of the Austrian State Railway (Pl. V, fig. 33);

2nd. Of a Bessemer rail, designed by the committee of engineers of that railway, and being only three quarters of the weight of the preceding rail (Pl. II, fig. 12);

3rd. Of an intermediate section designed by the Northern Company for steel, whether puddled or Bessemer, the weight being 0 · 83 per cent of the ordinary section (Pl. XXXII, fig. 10).

Admitting that the molecular resistances of the iron and steel are as 4 : 7, the breaking loads by deflection of the three sections are as 1 : 1·87 : 1·92.

In the third section, the height is $4\frac{3}{4}$ ins., as in rail N° 2; the breadth of the flange was increased from 4 ins. to $4\frac{3}{8}$ ins., by this increase it is proposed to guard not only against the flange becoming embedded in the sleeper, but also against the tendency to a reduction in the gauge, on straights, by an increase of the inclination of the rail. The thickness of the web was reduced to $\frac{1}{2}$ inch, and the weight of the rail to $62\frac{1}{2}$lbs. per yard, while the length has been increased to 21 ft. 8 ins.

The commission, already mentioned (342), of the Southern of Austria Railway is of opinion, that there is no room, in substituting steel for iron, for reduction in the section; it would even be inclined, like the Northern of Austria Company, to widen the foot.

The English Railway Companies, especially the London and North Western, which has adopted so resolutely the use of steel, have also preserved their original section of rail.

In France, the case is the same on the Northern, the Western, and the Orleans Railways; the latter company adding, besides, an eighth sleeper to the 19ft. 6 ins. rail on the inclines in crossing the Cantal, between Murat and Aurillac.

On the Mediterranean line, the substitution of steel for iron (348) is coincident with an appreciable increase of weight, from $74\frac{1}{2}$ to $80\frac{1}{2}$ lbs to the yard; but this excess of weight, due moreover in a small degree to the slightly greater specific gravity of the steel ($2\frac{1}{4}$ lbs. in a 19ft. 6 ins. rail), is not for the sake of strengthening the rail; the increase of section only applies to the width of the flange, which is enlarged to $5\frac{1}{8}$ inches (Pl. XXXII, fig. 9): if, however, this increase of width has the effect of distributing the load over a larger surface of wood, such was not the object for which it was done. It was intended simply to permit of the pegs inside being driven through holes in the flange, so that they might assist the spikes on the outside in resisting the thrust of the flanges. The outer spikes are, as usual, driven clear of the rail, but the symmetry of the latter requires the breadth of both sides of the flange to be equal. The other dimensions of the section are the same as those of the iron rail, so that there should be no difference to affect the joints and the fishing.

Even admitting the utility of such a connection between the inner and outer fastenings (37,207), it is at any rate doubtful whether it justifies so great an increase of weight, and one which causes absolute difficulties in manufacture.

The rail-section (Pl. II, fig. 12), proposed by a commission of Austrian Engineers (*), is a little lower than that of the Austrian State Railway; $4\frac{3}{4}$ instead of 5 inches. This reduction, slight though it be, is due to the greater strength of the steel. It is, however, criticized by other engineers who find, and not without reason, that rigidity is an essential quality, and that the reduction of height, entirely taken out of the web, does not effect an economy commensurate with its influence on the strength of the rail. This reduction appears to them but little warranted, at a time when most of the German Railway Companies regard an increase in the height of the iron rail as a necessary consequence of an augmentation both in the traffic and in the weight of the engines, the height of some of the rails being nearly $5\frac{1}{4}$ inches (new lines of the Main-Weser); to reduce the height is, say they, to be exposed to the necessity of prematurely relaying the line, or of strengthening, by the costly

(*) "Zeitschrift des österreichischen Ingenieur Vereins", 1865, p. 115; Herr Köslin, Secretary.

addition of new sleepers, rails still good but too weak to bear the loads brought upon them.

The Austrian Commission is of opinion, and doubtless not without reason, that the thicknesses may also be slightly diminished. The proposed rail has the same resistance to transverse fracture, as the iron rail of the Austrian State Railway; allowing the molecular resistances to be, 35 tons 18 cwt. per sq. inch for steel, and 20 tons 10 cwt. for iron (a proportion also admitted, as will shortly be seen, by the commission of the Southern of Austria). The weight would be, 55 lbs. to the yard, instead of nearly 75 lbs. The yearly saving would be indubitable under those conditions, even with a moderate traffic which attenuates the economic inferiority of iron. The commission, considering that the iron rails employed in Austria are of better quality than English rails of similar section, and that the durability of the Bessemer metal made in Austria is not yet ascertained, has not admitted a ratio so favourable to steel, as that, which observations made in England (353), warrant as a minimum. The commission has allowed for a durability only three times as great; an estimate undoubtedly dictated by excessive prudence. On the other hand, the reduction of weight of the Bessemer rail is, perhaps, carried a little too far.

Taking fifteen years as the duration of iron rails, and forty-five as that of Bessemer rails, the annual cost would, at the present rates, be reduced in the ratio of 1·55 to 1; without taking into account carriage and labour in maintenance, which is less felt with Bessemer metal on account of its greater durability.

In fine, the commission regards Bessemer metal as possessing advantages beyond dispute, and as being certainly superior to the figures admitted. It is also of opinion, that the old iron rails may be used up either in metallic sleepers, or in the longitudinal angle irons of the compound rail; an opinion somewhat personal, perhaps, to the author of the report, who is also the inventor of one of these types of rail (195). But it may at any rate be admitted, that the old iron rails will find a use, in one form or another, as supports for Bessemer rails.

350. *Manufacture of Bessemer rails. — France.* — The Bessemer process yields, with admirable simplicity and rapidity, a refined cast product, of perfect homogeneity, thanks to the energetic mixing effected by the air forced into the mass of molten metal.

But whatever be the advantages of this process, it can, like any other, only extract from the substance treated that which it contains; for obtaining true steel

with all its several characteristics, special steely pig iron is required, and the principle laid down a long time ago by M. Leplay, as to the special selection of ores being a necessary condition, independent of the method of treatment, is thus confirmed.

To this pig iron of superior quality a certain proportion of ordinary pigs, more or less impure, may doubtless be added, as in other processes (*), but the nature of the metal is necessarily influenced by it. In fact, what is required of Bessemer metal is less steel than molten wrought iron; a substance which seems, moreover, as if it ought to be turned to great account on railways. The steely nature of the ores is no longer requisite in that case; but unfortunately the purity of the pigs is always a necessary quality (364)

In France, the manufacture of Bessemer rails has only been developed to any considerable extent in three establishments : those of Assailly (Loire), Imphy (Nièvre), and Terrenoire (Loire). The special pig treated is obtained, in the first, from the magnetic iron ore of Saint-Léon (Sardinia); in the second, from the hæmatite ores of Bilbao (Spain), of Vicdessos, and of the Canaigou; in the third from those of Mokta-el-Hadid (province of Bone), and of Privas (Ardèche).

Hitherto the metal has not been run direct from the blast furnace into the converter, indeed, it could not be otherwise in works which, like those of Assailly and Imphy, do not possess blast-furnaces; but it is because this arrangement was regarded, if not as impracticable, at any rate as very difficult, that attention has not been turned to the laying down of converters alongside of the blast furnace.

By selection and re-melting, the uniformity of quality necessary to the regularity and success of treatment in the converter can with certainty be obtained. But there is no absolute necessity for this preliminary operation, far from it. Bessemer metal requires highly carburetted grey pig; and grey pig is the easiest to work in the blast furnace. Without speaking of the Neuberg works (Styria), or of those of Fagersta (Sweden), which constantly work with metal run from the blast-furnace, but with pig of superior quality, the same simple method is adopted at the Terrenoire works (Loire), with complete success. The colour of the slag is a sufficiently sure indication of the working of the blast-furnace; and it is only when the appearance of the slag shows that the furnace is in trouble that the metal is run into pigs to be sorted, and remelted in the reverberatory one. The direct treatment is also in operation at the Montluçon works (Allier), where the process has lately been started.

(*) It is thus, that the pigs obtained from the spathic ores, puddled at Allevard (Isère) for granular iron, can bear the addition of a moderate proportion of Bességes pig.

At Seraing (Belgium), according to M. Lebleu, « Ingénieur des mines », the charge comprises 85 per cent of Cumberland, and 15 per cent of German pig.

351. *Germany.* — The Bessemer process was adopted for the first time in Germany in 1859, at the works of Herr Krupp, Essen; according to M. Maurer, the steel works of T. Giesbers at Gemunde (Eifel) turned out in 1863 the first ingots which were rolled into rails at the Lendersdorf works. The converter is at work at Hörde, at Bochum, at Königshütte (Upper Silesia), at Turrach, at Grätz and at Neuberg (Styria), at Heft (Carinthia), at Prävali, at Oberbilt near Dusseldorf, etc.

As the Grätz works, where the author has seen rails entirely of steel turned out, as well as composite ones (342), are not provided with blast-furnaces, they cannot, like the neighbouring Government establishment at Neuberg, work by the direct process. Mr Hall does not regret this, however, as, in his opinion, it is better to work with pig iron, the homogeneity of which may be determined, and which can, if necessary, be selected. The example of Terre-noire, that of Neuberg which uses direct from the blast-furnace the same metal as Grätz, that is to say pig smelted from spathose ores, prove that, if this opinion is correct, it is not yet absolutely settled.

Particular attention is given at Grätz, in the final addition (of the carburizing substance), as much to the proportion of carbon as of manganese in the spiegel, if indeed more attention is not paid. According to Mr Hall, the steel is better in proportion as the spiegel is rich in carbon. The mean proportion is 8·5 per cent, and the proportion of spiegel added 7 per cent; the metal is run without stopping the blast. At Neuberg, no special pig is added, but some is used from the blast-furnace itself.

The committee of the Southern of Austria (342) is of opinion that the hammering of ingots is useless, at any rate in the case of those obtained from Grätz; the increased cost not appearing to be compensated by an appreciable improvement of quality. The ingot is therefore heated, and rolled into a rail at a single heat, being afterwards sawn at both ends while still hot. The crop ends are used up in the piles for composite rails.

Besides, the object of the manufacture at Grätz of rails entirely of steel, has hitherto been rather a study of the question than a commercial production. In this trial, much attention has been bestowed upon one of the problems of the future, that of the working up again of old Bessemer rails. In Mr Hall's opinion, they will most likely have to be treated like old iron rails, that is to say by piling. It will, therefore, be advisable to guard against difficulties of

manufacture, and against grave defects, by henceforth paying particular attention to the production of an easily welded metal.

It is, besides, well known that the old Bessemer rails may be charged into the converter, after being raised to a red heat, in a certain proportion which some engineers make as high as one-third. But, hitherto, very little more than crop ends have been worked up again, and that in very small quantity; more frequently, indeed, they are re-melted in pots; Bessemer steel works having generally a steel foundry attached, such, for instance, is, in France, the case at the Imphy works. This practice is costly, although the reverberatory-furnace, capable of taking several pots at once and heated by coal, is often substituted for the blast-furnace heated by coke; but the direct treatment in the Siemens reverberatory-furnace, already applied by M. Martin (365) would seem to be the most simple and economical method for dealing with the old rails, waste, and crop ends of the Bessemer process.

At Prävali, the ingots, reheated to an orange-red, pass three times through the first groove of the cogging rolls (there are three roll-trains), twice through each of the two next, and twice through the first groove of the roughing rolls. They are then again heated and passed once through each of the eleven following grooves of the roughing and finishing rolls. They have, therefore, twenty passes altogether.

At Herr Krupp's works, Essen, the steel for rails is run in ingots, each of which forms four rails: this method has the advantage of diminishing the number of crop ends, which are irrespective of the length of the ingot. The operation of rolling is preceded by a sharp hammering.

The Bochum rails are of superior quality, but are also dear. They are exclusively made from Cumberland pig, the cost price of which exceeds by more than 80 per cent that of the native brands worked up at Essen and Hörde. The ingots are hammered.

352. *England.* — The manufacture of Bessemer rails has been more largely developed in England than elsewhere. The activity of the traffic on her numerous lines, and the frequently poor quality of the English iron rails, render the use of a more durable substance still more necessary in that country than elsewhere; and on the other hand, England has found in the hæmatite ores of Cumberland a very pure raw material which enables her to trust to her own resources, so as to be dependent on other countries only for the additional pig. She even tried to be independent of this aid, though she still accepts it. Through her maritime and commercial power, she has, besides, been called upon to supply the new material to foreign lines, and especially to those of the United States, which quickly adopted the Bessemer

rail. Since the year 1865, Sir John Brown and C° of Sheffield have delivered 8,000 tons to the Pennsylvania, the Erie, the Philadelphia, the Baltimore and Ohio, the Chicago, the Philadelphia and Reading, and the Lehigh Valley Railways. The manufacture of Bessemer rails is, besides, beginning to be developed in the United States; but, as their railways still obtain from England some portion of their iron rails, doubtless the same course will be pursued, for some time, with a material on which the charges for transport will be less felt on account of its greater intrinsic value.

Notwithstanding the resources of these special works, one of the most important railway companies of Great Britain, the London and North Western, has not hesitated to erect at its large shops at Crewe, works by which it may turn out Bessemer steel for itself — a material of which it uses large quantities for its rolling stock and permanent way, but especially of course for the latter. The mottled pig there used is obtained almost exclusively from the Cumberland red and brown hæmatite ore; it is remelted in the reverberatory-furnace.

According to M. Grüner (*), the ingots, weighing from $4\frac{1}{2}$ cwt. to 5 cwt., are re-heated in an upright position, in a Siemens reverberatory-furnace with a revolving bottom. At first they were hammered, but now they pass at once to Ramsbottom's oscillating roughing rolls, in which six or seven passes are made. After a second re-heating, nine or ten passes are made in the finishing rolls, arranged like the roll trains for iron rails.

At Sir John Brown's works, Sheffield, a mixture of Derbyshire, and, it is said, of Swedish pig, is charged into the cupola and thence run into the converter. The proportion of spiegeleisen is slight, 4 per cent at most; the metal is also run, too, almost immediately without stopping the blast; the ingot is hammered (at any rate it was on the occasion of the visit of the author in September 1865), re-heated, and rolled into a rail; the two ends are sawn off one after the other; the rail after being straightened and cooled, is planed to the standard length.

At Dowlais, the bath (**) comprises $\frac{3}{4}$ of Cumberland hæmatite ore and $\frac{1}{4}$ of roasted argillaceous ore of the coal-measures, pure, and also containing manganese. The resulting pig is treated in the converter with an equal weight of hæmatite pig. The charge of the converter consists of $4\frac{1}{2}$ tons of pig to which is added from 5 to 10 cwt. of steel rail ends. The addition of the spiegeleisen, from Westphalia, containing on an average 8 per cent of manganese, is from 6 to 7 per cent. A great point is made of obtaining the steel soft, which rolls

(*) M. Grüner, *op. cit.*, p. 249.
(**) " " *op. cit.*, p. 246.

more easily and is as good for rails as a harder quality. The proportion of carbon is only about 0.15 per cent. These rails therefore approach more nearly to " homogeneous metal " than to true steel.

Formerly the ingot was first hammered; but it has since been considered, as at Grätz and at Crewe, that without hammering a quality might be obtained, if not quite as good, at any rate sufficiently so. The ingot passes through three pairs of rolls : 1st the blooming with four large square grooves; 2nd the roughing, with seven groves also square; 3rd the finishing, with five grooves. Two passes are made through the last groove.

Although cylindrical ingot-moulds are more convenient as far as the pouring of the metal is concerned, the form of a prism is preferred as easier to roll.

353. *Comparative duration of iron and Bessemer rails.*—The observations made in England, on the manner in which Bessemer steel rails stand are so well known, that it is almost superfluous to reproduce them; it will suffice to mention the instance so often quoted, of the Camden-Town Station of the London and North Western Railway, a point at which an enormous traffic is concentrated, especially on certain pairs of rails. Fifty-two rails obtained from ingots cast at Mr Bessemer's works, Sheffield, and rolled at Crewe, were laid down there in March 1862. Each steel rail had an iron rail laid opposite to it in the same piece of line, so that the conditions to which each was subjected were identical. Two of these rails had been laid near the Chalk-Farm bridge, the point most subject to wear in the whole group of lines at Camden. In August 1865, one of these rails was taken up to be exhibited in Birmingham at the meeting of the British Association, as unanswerable evidence of the value of Bessemer metal as compared with iron, and was submitted to various tests. It had been found necessary to replace its fellow iron rail eight times after turning and complete destruction of both tables, while the steel rail, not turned, had only undergone a slight wearing away. One steel table, then was still capable of long service, after having been subject to action which had destroyed sixteen iron tables.

The second rail, kept in its place, was still in good condition and not turned, while the corresponding iron rail had been replaced eleven times. (This number would give to the iron rail a duration of five months and half; but its average duration at this point is only four months.)

The twenty-third iron table was almost worn out when the second rail was broken in consequence of a violent collision between two engines; the rail had been broken by the engine upon it into three pieces, by a blow applied in the most unfavourable manner, that is to say horizontally. The very appearance of

the broken rail bore evidence of its great power of resistance: the piece which had received the shock had only detached from the two others after an enormous deflection (Pl. XXXII, fig. 26).

254. *Influence of cold.* — Mr James Livesey in some remarks made by him before the Society of Arts of London, stated, that some very hard rails sent out from England to Canada, had experienced many fractures during a severe winter; whence there had arisen a certain amount of mistrust in Bessemer metal, and attention was again turned to the steel-headed rail. This mistrust was unfounded; as recent experience proved, that the percentage of fractures with steel rails was much less in Canada than with iron ones. If however in the United States some engineers withheld their confidence in the Bessemer rail, they constituted only a small minority.

The relaying in steel of the Hudson Railway had been, it is said, decided upon; and Mr Bridges, director of the Grand Trunk of Canada, insisted strongly on the application of the Bessemer rail to this line. Far from frightening him the rigour of the climate was with him only an additional reason for this course. For many years, too, Mr Ramsbottom has studied the influence of cold on Bessemer rails. On one of the coldest days of the winter of 1861-62, he tested several with the ram, but without succeeding in breaking them.

A report, addressed on the 3rd March 1868, by Mr H. Riddle to the President of the Erie Railway, which is among the foremost in the United States for activity of traffic, contains information of great interest on the insufficient strength of iron, under the conditions to which it is subject on this line, and on the superiority—indeed the necessity—of steel, precisely under the influence of such severe climates. During the hard winter of 1867-68, which completely prevented any maintenance of the line, the destruction of iron rails supported by a frozen ballast, hard as a rock, reached unprecedented proportions. Fractures, crushing, splintering, and as an inevitable consequence, the fracture of wheels and axles, and running off the line (*) became so frequent that it was found necessary to reduce the speed of passenger trains at several points to 15 or even 12 miles an hour. During the month of January, 1,000 broken rails, and a much larger number still of rails, rendered unfit for use by the crushing or the deterioration of their heads, had to be taken up; and in the month of February the state of things was still more disastrous.

(*) The running off the rails, attended with such disastrous consequences, which took place on 15th April, 1868, on the Erie Railway, and which cost the lives of a large number of passengers, was caused primarily by the fracture of an iron rail.

"By the experience of this winter, I have acquired," said Mr Riddle, "the con-
"viction that iron, under the conditions of weight and quality adopted by us, is
"insufficient to support the traffic of our line; in such a state of things, where must
"we seek a remedy? Evidently in the *largest possible use of steel*, — in the adoption
"of an iron rail of greater weight and better quality, — and lastly, in the reduction
"of the weight of engines and wagons; a weight which has increased of late years
"to an extent out of all proportion to the construction of the permanent way."

Bessemer rails, from Sir J. Brown & Co. Sheffield, were laid down on ten miles of way, and stood very well; one only broke during the winter, and the alteration of their section was scarcely appreciable.

Mr Riddle concludes, in fact, that 25,000 tons of rails were in 1868 necessary for the relaying of the line, and he again insisted that steel shall enter into this figure "to the largest extent possible." Evidence much more significant in favour of Bessemer metal is afforded by the high import duty imposed in the United States, almost equal to its price in England.

The introduction of Bessemer rails into North America (especially into Canada) is, then, not merely a question of economy; it is also a question of safety, an element not held quite so cheap in America as we are every day told it is; serious attention is, however, only payed to it, after having provided for what they consider more important. The line must work, at any cost; safety is an after consideration.

355. Steel rails have often been the subject of a reproach, which would be serious if well founded; a diminution of adhesion, on account of the smoothness of the surfaces. Practical experience would not appear to justify this fear. M. Riggenbach, engineer of the rolling stock of the Central of Switzerland, whose province included the Hauenstein incline on the Jura, assured the author that the tendency to slipping had in no way been increased by the introduction of steel rails on that incline, of 1 in 48. The fact stated by this eminent engineer is of so much the more importance, as in this case the adhesion of steel upon steel is in question, the engines being provided with Krupp tyres.

356. Several English engineers assert, that resistance to traction is much less on a steel than on an iron way. Hitherto, this opinion has rested on no precise experiment, but it is probably correct; since steel rails only take a permanent set under much greater loads (363), and as their wearing surface remains almost intact, resistance to traction ought on that account to be in some measure reduced.

357. *Conditions of manufacture and delivery.* — If the conditions imposed

by specifications for the manufacture of iron rails, obtained by old and well known methods, are often open to criticism, it is natural that, in the case of the Bessemer rail, these conditions should be affected by the novelty of a process which constitutes quite a revolution in the iron manufacture. Although we still find well marked in this process the phases and reactions of puddling, but of an extremely energetic both chemical and mechanical puddling, no determination has yet been arrived at as to the exact action—favourable or injurious—exercised by several of the elements present; nor have the qualities been exactly defined, which should be possessed by the cast metal to be converted into rails. Besides, these first specifications can only be regarded as rough draughts, which experience will modify; and certain, somewhat inconsidered, conditions contained in them might sometimes lead to difficulties in execution, unless tempered by a wise latitude.

Extract from *The Specification of the Paris, Lyons and Mediterranean Railway.*

* * * * *

Art. 4. The rails shall be exclusively made by the Bessemer process.

The operation shall be conducted in such a manner as to yield steels of the best quality, fine-grained, compact, homogeneous, and equal to samples, which are to be sent to the Company by the manufacturers, and agreed to by the Company's engineer.

According to instructions (which will be sent to the manufacturers) as to the execution of orders, and in keeping with the requirements, the manufacture shall be carried on in such a manner as to yield steel of different degrees of density; according to the use for which the rails are intended.

Cast steel shall be run in ingots $8\frac{1}{2}$ inches thick by $7\frac{3}{4}$ wide, in ingot moulds made in two halves, so as to avoid a conical shape in the ingot.

After fusion, the ingots shall be carefully examined; and those which show any air-bubbles, cracks, cinder, or other defects that cannot be got rid of in rolling, are to be rejected.

The rolling shall be performed in such a manner as to give the perfect form of the rail, with smooth and flat surfaces; and especially so as to avoid the twisting, which often takes place on the rail leaving the rolls.

The bars or ingots which show, either on the exterior or in the interior, any layers having doubles or breaks in them shall be rejected.

The bars shall be perfectly straight throughout their whole length, without deflection in any direction, so that they may be laid down without previous straightening. They shall be straightened, as far as possible, while hot, on leaving the rolls, on a cast iron plate, and then laid for cooling on a horizontal bench with solid foundations. The operation of cold straightening, if employed, shall be performed gradually by pressure, and not by blows.

The bars shall be cut at each end, at a sufficient distance from the rough ends, so that the extremities of the finished rail shall be perfectly sound. The rails shall be

cleanly cut, either cold, by the lathe, planing machine, shaping machine, or slotting machine; or hot, on leaving the rolls.

The removal of the ends, after reheating, by the saw or shears is distinctly forbidden. When the rails are sawn on leaving the rolls, the ends shall afterwards be tool-dressed.

The operation of cutting and dressing the ends shall be conducted in such a way, that no change in form of the ends shall take place by removal of metal or otherwise.

The planes of the two ends shall be exactly perpendicular to the axis of the rail.

The ends of the rail shall have all burs removed, by the rough file, or by the chisel and file, but they shall, under no pretext, be made good by hammering.

The holes in the web and in the foot shall be drilled; but the Company reserves to itself the right to authorize them to be punched according to circumstances.

* * * * *

Tests (art. 5).

The rails shall be carefully classified for each discharge of the Bessemer converter. A test ingot shall be run at each blow, and afterwards rolled into a bar an inch and a half square. The section of the test ingot before rolling shall be in the same proportion to the section of the bar, as the section of the rail ingot is to the section of the rail, that is to say about 4 ins. × 4 ins. The inspectors of the Company shall subject this bar to such tests as they shall think fit, in order to ascertain the quality of the steel and to assure themselves that it fulfils the stipulated conditions.

The Company reserve besides, the right to have run, from some blows, a rail ingot capable of being rolled into a rail of a minimum length of 8 ft. 3 ins; and to subject this rail to the following tests:

1st. The bar, placed upright on two supports 3 ft. 3 ins. apart, must sustain for five minutes, in the middle of the space between the supports and of the length of the bar, a load of 20 tons, without taking a permanent set of more than 0,01 inch.

2nd. The same bar, under the same conditions, must support, without breaking, a load of 40 tons applied in the centre. This load is then to be increased until fracture ensues.

3rd. Each of the two halves of the bar, laid on two supports 3 ft. 7 ins. apart, must stand, without breaking, the blow of a ram weighing 6 cwt, falling through 6 ft. 6 ins. in the middle of the distance between the supports.

(The conditions for the foundations of the supports are the same as for iron rails (23)).

4th. *Tempering test for hard rails.* — A piece about 8 inches long, either of a rail, or of the test bar, shall be broken off, heated to cherry redness, and hardened in a current of clean fresh water. It must take a hard temper; the surfaces must be polished, perfectly clean, and not capable of being acted on by a file. If the steel is of suitable quality, it should during its immersion, produce a strong bubbling noise and detonations, and the piece should split in several places. It is afterwards to be broken in the middle to ascertain the degree of temper.

With a piece from the same rail, or from the test bar, a half-flat bar shall be drawn out, an inch wide by three-quarters thick, which shall be subjected to the same tests as the piece mentioned above.

The results must be identical, except that, after the hardening, the grain of the fracture must be of finer texture, than that of the same sample not hardened.

5th. *Tests for steel in the form of tools.*— From a piece of the same rail or test bar shall be made, either hand chisels, or tools for the lathe, the slotting machine or planing machine. These tools, tempered in the usual manner, must, without becoming blunt, without flying, or turning up at the edge, take off the skin of white pig castings.

When the rail shall have satisfied all these conditions, impact and bending tests shall be applied to the corresponding bars; and the results ascertained must be obtained with the test bars of other charges, in the case of which there shall have been no direct test on the rail, with the exception of an allowance based upon the resistance of the tested rail.

If the required resistance, either of the rail or of the test bars, be not obtained, the whole of the rails from that blow shall be rejected. In the latter case however, the manufacturer may claim a trial of the rail itself; and, if it fulfil the conditions of resistance, the batch will have a right to be accepted.

Art. 6. * * * * *

Up to the time of their being handed over to the agents charged with the provisional acceptance, the rails must be kept in a dry place and free from oxidation.

Rejected rails are to be broken or stamped with an ineffaceable mark.

The final acceptance to take place three years after the laying down of the rails. Five per cent at least of the rails, composing the delivery, taken at various times, at the option of the Company during the execution of the order, shall be laid down by them on such points as they shall choose, on the main lines of their system that are most run over. This choice of situation for the trial rails shall not be subject to any restriction, either as to the number of trains, or as to the gradient of the line. At the expiration of three years wear to these rails, the proportion of damaged rails shall be jointly determined; and this proportion shall apply to the whole delivery, and shall determine the number of tons to be rejected.

For each ton of rails thus rejected, and without taking into consideration the short lengths that may be saved, the contractor shall pay to the Company, an indemnity of £12·12s. if the Company deliver the old rails to the contractor, and an indemnity of £7·16s. if they prefer to keep them wholly or in part.

Art. 7. The new rails shall be delivered in trucks at the station nearest the works.

Art. 9. Their price shall be £12·12s. per ton, which shall include the royalty due to Mr Bessemer (*).

Extract from *The Specification of the Orleans Railway.*

Double headed rail of the same section as that of the iron rail.

Art. 7. * * * * *

The inspectors shall choose out of each class (obtained from the manufacture of

(*) This royalty, £2 per ton, was reduced to £1 in the case of rails.

one or several days) a certain number of rails (one for every fifty or more), and subject them to the following tests:

1st. Each of these rails placed upirght on two supports 3 ft. 7 ins. apart, must sustain for five minutes, in the middle of the space between the supports, a pressure of 16 tons without appreciable set remaining after the test.

2nd. The same rail, in the same position, must sustain for five minutes without breaking, a load of 35 tons, which may be afterwards increased until fracture ensues.

3rd. Each of the two half rails, laid upright on two supports 3 ft. 7 ins. apart, must stand, without breaking, the impact of a 6 cwt ram, falling through 6 ft. 10 ins. onto the rail midway between the supports, with the ordinary testing machine of the Orleans Company; and falling through 4 ft. 10 ins. with that of the Mediterranean Company.

4th. *Tempering tests.*—This test will be applied to bars $\frac{3}{4}$ ins. square, forged out of a piece of rail. These square bars, heated to a suitable degree, must fly in hardening. Bars, 1 inch by $\frac{3}{4}$ inch, must also be hardened, and subsequently present a clean fracture and an appreciably finer texture.

If one of these bars should not stand the tests, they are to be continued on a larger number of bars; and, if more than one-tenth of the bars tested shall not stand the test, the whole batch of rails from which the test bars were taken shall be rejected.

* * * * *

258. *Proportion of carbon. — Its influence on resistance to fracture.* — There is, in the manufacture of Bessemer rails, an essential element to be determined, and that is the degree of hardness or decarburation proper to be given to the metal. Prolonged observation can alone determine this amount, and permit companies to be more explicit on this point in their specifications. Hitherto, but trials have been made; and the railway company leaves it somewhat to the manufacturer, who especially aims at ease and cheapness of manufacture.

Soft qualities of steel are only to a small extent affected injuriously by heat. They may be re-heated almost as easily as puddled iron. They are, it is true, less fluid, and become more sluggish in the ladle. On the other hand the less pure the metal, the less carburetted is the product generally turned out by the works; with an equal percentage of carbon, the metal is, in fact, so much the less capable of being welded, and — a more important matter where rails are concerned — so much more brittle in proportion to the presence of foreign substances. The thing is, in fact, to bring the final decarburation to such a point that the head of the rail shall be sufficiently hard, and yet that the rail generally shall not be too brittle.

Hard steel has a considerable statical resistance, but only a slight elongation before fracture.

Cast iron contains from 2·5 to 7 per cent of carbon; steel, from 0·375 to

2 per cent; wrought iron from 0·125 to 0·5 per cent. Steel and wrought iron then would appear to keep pace together, in such a manner that the proportion of carbon is not absolutely dependent on the double and different character of steel; that is to say its ability to be tempered and forged. With even 1.5 per cent of carbon the steel is very hard. The proportion of 0·45 or of 0·5 at most, which nearly corresponds to the point of transition from steel to iron, would appear to be the best for rails; it retains sufficiently both its hardness and its power of resistance. This proportion of 0·5 per cent was adopted by Mr George Berkley for a large order (22,000 tons) for the Great Indian Peninsula Railway.

A series of products obtained at various works, represented by proportions differing more or less, cannot be exactly compared, so that no precise conclusion can be arrived at by their simple comparison. It is, however, certain that the degree of hardness adopted for rails differs considerably between different establishments. Thus at Grätz, the steels are classed in six numbers; N° 1, the hardest, corresponds to a proportion of carbon equal to 0·5 per cent, and N° 6 is almost soft iron. The commission of the Southern of Austria (342) came to the conclusion, that N° 5 $\frac{1}{2}$, corresponding to an extremely soft steel, is that most suitable for rails. At Terrenoire, on the contrary, the steel for rails belongs to the second of the four classes, still imperfectly defined however, which have hitherto been produced there; the tipping takes place immediately after the addition of the spiegeleisen; it did at least when the author was present. The converter is not raised up again. As an example of an excessively slight proportion of carbon, a rail-ingot at Dowlais may be cited; which according to Mr Parry, the engineer at the Ebbw-Vale works, contained only 0·15 per cent of carbon (*).

The Camden Town rails (353), almost of classic fame, were not analysed. In the opinion of some engineers, they were more highly carburetted than the greater part of those now manufactured. If this was the case, the latter will not perhaps give such satisfactory results; their wear, it is to be feared, will be less slow. As to transverse resistance, the Chalk Farm rails should satisfy the most exacting.

Steel for cast parts, such as crossings (277) should also be soft; less so however than rail metal. The proportion of carbon may be as high as 0·75 per cent. Above that, the steel would possess in a still higher degree the quality of hardness, especially useful for the various appliances of the

(*) M. Grüner, *op. cit.*, p. 247.

permanent way; but it would be at the expense of their resistance to concussion. Below this point the temperature of fusion would be higher; and the difficulties already serious, which have to be overcome to obtain sound castings, would be aggravated.

359. Manufacturers now know how to obtain, almost continuously, with the same pig a constant product. Notwithstanding the hurried nature of the operation, its characteristics are sufficiently defined for a practised eye to be able to dispense with all other guides than the appearance of the flame. It is sufficient to follow carefully the different phases of the operation, to regulate the pressure of the blast, to seize the moment when the spiegeleisen should be added in a predetermined proportion, and lastly to determine the duration, always very short, of the reaction between the spiegel and the refined metal.

Spectrum analysis is often only regarded as an object of curiosity in those works, where it has been introduced.

Thanks, however, to the researches of Herr Liellegg, the spectroscope has at Grätz recently become a very useful auxiliary; it permits of seizing upon the precise moment when the operation is complete, and therefore of fixing the exact proportion of spiegeleisen necessary to obtain a given quality of metal. The appearance of the sodium line, so visible and so persistent in the yellow of the spectrum, indicates the commencement of the decarbonization. The connection between these two circumstances arises from the fact, that the spectrum only attains its complete development on the combustion of the carbon.

As soon as this line appears, which continues until the end of the operation, the characteristic carbonic oxide lines also show themselves; chiefly in the green portion, which is the standard point of observation. There the lines are more brilliant and sharper, appear sooner, and disappear later than in the yellow and the violet, as well as in the red and the blue, where they also are seen. After the boiling, their intensity is at the maximum. Four or five minutes before the end of the operation, for a charge of about three tons, they begin to be indistinct. When the last has disappeared the spiegeleisen is added; sometimes, however, this addition is made when one or even two lines still remain in the green band. The essential matter, however, is that the proportion of spiegel should be imparted at the proper moment. This characteristic is much more sharply defined, than are the variations in the appearance of the flame.

These remarks only apply to the charcoal pig of Styria as treated at Grätz; with other classes of pig the rule will perhaps vary in detail, but it is very probable that the process is capable of general application.

An indication is also afforded (*) by means of test samples of the slag; a method which evidently requires that the converter be turned down, and the blast stopped. The cooled sample has a much deeper tint as the operation advances; and it is when the slag is almost black on the surface and of a light green in fracture, that the decarburizing pig should be added.

360. The following, according to the Terrenoire and Bességes Company, are the resistances to tensile strains and the elongation at fracture of their steels:

	RESISTANCE in lbs. per sq. inch.	ELONGATION at instant of fracture per cent.
Hard Bessemer metal for rails.	88,181	7·5
D° D° D° for axles.	113,782	7·5
Soft D° D° in bars.	79,647	11·5
Ordinary granular iron.	51,913	13
Ordinary fibrous iron.	46,224	19

The superior strength of the metal for axles, notwithstanding its ductility being as great as that of rail steel, is explained by the fact of the different mixture of ores. In steels obtained from the same pig, and differing only in the degree of refining, the elongation is appreciably in inverse ratio to the resistance.

The mean of nine experiments to fracture by tensile strain, made on rails of the Great Indian Peninsula Railway (358), manufactured by Sir John Brown and C°, gave 100,299 lbs (44·75 tons) to the square inch; a very satisfactory figure, provided it be not coincident with a certain shortness of the metal, which however is not likely to be the case.

Mr T. E. Vickers communicated in 1861 to the Institution of Mechanical Engineers, when at Sheffield, the result of a number of experiments for determining the influence of the proportion of carbon on the strength of steel. The steels on which he experimented were obtained, not from the converter, but from the crucible. It is, however, no less useful to reproduce a few of the results obtained by him; as this difference of process does not affect the point in question, that is to say the influence of the percentage of carbon. The experiments were made on gauged bars, 21 $\frac{1}{2}$ inches long, of which 14 inches

(*) M. Grüner, *op. cit.*, p. 265.

were turned down to a diameter of 1 inch; the loads were applied by means of a lever the arms of which were in the ratio of 1 to 20. From the data given by Mr Vickers, the author has compiled the following table.

1	APPROXIMATE percentage of carbon. 2	SPECIFIC gravity. 3	BREAKING strain in lbs. per square inch. 4	PROPORTIONAL elongation before fracture. 5	PRODUCT of the load and the proportional elongation. 6
				per cent.	
Swedish iron (very pure)..	»	7·894	»	»	»
Iron from which the following steels were obtained.	»	7·860	»	»	»
Steel N° 2..........	0·33	7·871	67,985	9·8	666,253
— 4..........	0·43	7·867	75,950	9·8	744,310
— 5..........	0·48	7·855	83,630	9·0	752,670
— 6..........	0·53	7·855	95,151	8·0	761,208
— 8..........	0·63	7·848	100,555	7·1	713,941
— 10..........	0·74	7·847	101,693	4·9	498,296
— 12..........	0·84	7·840	122,316	8·0	978,528
— 15..........	1·00	7·836	133,837	7·1	950,243
— 20..........	1·25	7·823	154,317	4·4	678,995

Bessemer steel may easily attain these last amounts of resistance. According to M. de Cizancourt, Ingénieur des mines (*), the Bessemer steels, tested at Woolwich by Genl E. Wilmot, also sustained more than 63½ tons per square inch; but the elongations, which must have been very slight, were not given.

Resistance to tension increases regularly with the proportion of carbon, but only, says Mr Vickers, so long as this proportion does not exceed 1·25 per cent; above that point it diminishes, he says, until the metal, which is then cast iron, only supports from 6 tons to 6½ tons. per square inch.

He also points out a fact, which it will be well to notice in passing, as a warning against comparisons so often made between the results of experiments carried out under different conditions. Some bars, where the section reduced by turning extended only for a very short length, supported per unit of sectional area much more considerable loads than those just mentioned. It is evident, that the chances of the existence of a weak point, of a slight defect in the metal, increase with the length of the portion reduced in sectional area. But, according to Mr Vickers, this length has a direct inevitable influence on the resistance. He has, in fact, noticed that the longer the turned portion, the

(*) "Annales des Mines", vol. IV, 1863, p. 268.

more is the metal drawn out, and the more contracted does the sectional area become on fracture.

Though the elongation at fracture generally diminishes when the proportion of carbon increases, yet it does not do so in a regular manner. The products of the elongation by its corresponding resistance, that is to say their power of resistance, vary independently of the proportion of carbon (see column 6 of preceding table).

As indicated by column 3, these experiments seem to invalidate the opinion generally received, that the specific gravity of cast steel, untempered, is higher than that of wrought iron (349). But, it is perhaps only an apparent contradiction; it has arisen doubtless from the fact, that the steel was obtained from relatively pure iron, the specific gravity of which is greater than that of impure iron. Steel should be compared with the iron from which it is obtained. This is what Mr Vickers has done; he has experimented on a very pure iron, and he has ascertained that the specific gravity, maximum in the case of this iron, decreases gradually in the steel obtained from it, in proportion as the percentage of carbon increases. But in the case of impure iron — and the iron of rails is so — this specific gravity may be as low as 7·644; it is then notably inferior to that of steel even containing 1·25 per cent of carbon, obtained from an iron much more pure.

Mr Vickers thinks, in fine, that steel containing from 0·63 to 0·75 per cent of carbon is more suitable for the majority of applications, and for all except those special requirements which demand, either a great ductility, or considerable hardness. But this proportion is, as a rule, far from being attained in rails produced by the converter.

The preceding results agree with those obtained in Sweden, where the research of the proportion of carbon is of usual occurrence at the works; and where indeed it is of especial importance on account of the purity of the iron, the properties of which are not much modified except by the carbon. With 0.35 per cent, the only characteristic which distinguishes steel from iron, that is to say the property of tempering, commences to show itself, and is very manifest at 0·8; 1·4 is the upper limit, which is applied only to very few uses.

361. *Inequality of resistance to fracture in tension and in compression.* — The Bessemer steels from the Fagersta Works (Sweden), justly noticed at the international exhibition of 1867 (*), were the subject of numerous experiments

(*) The exhibits from Fagersta comprised a series of samples, marked as having undergone from 1 to

by Mr Kirkaldy. In transverse deflection, he ascertained that the neutral axis at the instant of fracture varies with the proportion of carbon. The harder the steel is, the nearer is this axis to the extreme fibres in compression; that is to say, the ratio of the resistances to fracture by compression and by tension vary with the hardness : the former resistance exceeds the latter in proportion as the degree of carburation is higher. It is, however, quite natural that steel, an intermediate product, should approach more or less, according as this degree is high or low, either to wrought iron, wherein the two molecular resistances are practically equal; or to cast iron, wherein the resistance to fracture by compression is much greater than by tension. But, according to Mr Kirkaldy, the resistance to compression, much greater in the hard steels of Fagersta than the resistance to tension, would become not only equal to it, but even less, in soft steels, which would cease to be intermediate between cast and wrought iron; in which last the two resistances are practically equal when the experiment is made in such a way as to counteract the bending, which tends to give an apparent inferiority to the compressive resistance.

The late Sir Wm Fairbairn, who has carried out numerous experiments on the best Bessemer steels made in England, ascertained : 1st that their resistances to fracture by compression and by extension are on an average 100·7 and 47·7 tons to the square inch respectively, or as 2·1 to 1 nearly (these direct experiments have been confirmed by fractures due to deflection); 2nd that their resistance to tensile strain is itself double that of the best English irons; 3rd that the elongations at fracture by tensile strain, very variable in themselves, are in fact much less than is generally supposed. The greatest figure obtained by Sir Wm Fairbairn, 0·1437 per unit of length, is inferior to the mean figure given by the irons that were tested, and the smallest is only 0·0037.

In symmetrical double-headed iron rails, fracture always takes place in that portion of the section which is subjected to tension (338); so that, in view of the inferiority of the resistance to this strain in steel, an unequal-headed rail would be more defective still with this metal than with iron (33).

362. *Elastic Resistance.* —The coefficient of elasticity of cast steel presents, like that of wrought iron to which it is but little superior, variations of considerable range; and which are not connected by any law with the other mechanical

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50 pilings and re-heatings without losing their nature or their steely quality. It is well known, that this is the weak side of Bessemer metal, which generally loses its nature by repeated piling.

It is not astonishing, however, that steels obtained, like those of Fagersta, from superior pig escape this defect. The re-heating took place, besides, in a gas furnace.

properties of the metal. Tempering itself, which exercises so great an influence on resistance to fracture, and on the point at which the elasticity commences to be sensibly impaired, has no influence on the coefficient. Some cast steel plates of Messrs. Petin and Gaudet, tested at the "Conservatoire des Arts et Métiers" (*), in Paris, showed values, in lbs square inch, comprised : in the case of the hard steels, whether annealed or not, between $10^6 \times 26{\cdot}74$ and $10^6 \times 30{\cdot}68$; and in the case of the soft steels, both tempered and not so, between $10^6 \times 18{\cdot}42$ and $10^6 \times 30{\cdot}20$. In experimenting in his turn on blades of English cast steel of first quality, for watch springs, whether hardened or not, M. Résal (**) has obtained values comprised between $10^6 \times 24{\cdot}18$ and $10^6 \times 31$; limits very nearly approaching those ($10^6 \times 24{\cdot}47$ and $10^6 \times 30$) at which M. Wertheim arrived.

If, then, it may be said in practice that the elastic resistance of cast steel is superior to that of wrought iron, this must be understood to apply especially to the more considerable strains requiring a marked alteration in the elasticity. The coefficient is appreciably the same, but it is maintained, in the case of the steel, through a wider range of loads. If with equal sectional area and load, a steel rail deflects less than an iron one, this is so only under loads exceeding the practical limit (22) of elasticity of the latter, and not reaching it in the former (***).

363. The condition of using, in order to obtain true steel by the Bessemer process, at least a considerable proportion of special pig obtained from steely ores is perfectly simple. It is common to all the processes; that of Mr Bessemer is subject to it like the others. But it is not merely steel, that is to say a metal capable of being tempered, that is required of the converter; it is especially a cast product, perfectly homogeneous, very often more allied to soft iron than to steel. In which case, there would seem to be no reason why pig obtained from any ores whatever, provided it were grey, should not be treated by the Bessemer process. But these attempts have failed; the converter, so suitable to the elimination of the carbon, and of the silicon which is one of the essential agents of the operation, exerts less influence than ordinary puddling on the other foreign substances, and especially on the more tenacious and

(*) "Annales des Mines", vol. XIX (1861), p. 345 and fol^{g}. Art. by M. Tresca.

(**) "Annales des Mines", vol. XIII, 1868, p. 118.

(***) The value, 42,000,000, which appears in different collections of tables, and which would apply to "a very fine cast steel, tempered, and annealed in oil", without any indication of its origin and without the guarantee of the name of the experimenter, would then appear to be an exception; not to say an anomaly.

at the same time the more injurious of them, sulphur and especially phosphorus. Besides, excepting only by a previous operation (365) can those classes of pig be treated, where these two substances enter in more than very slight proportions; as to what they are, opinions are not agreed. Thus, while at Hörde the maximum proportion of phosphorus in pig to be treated by the Bessemer process is fixed at 0·06 per cent, pigs are used at Neuberg which, according to Herr Tunner, contain 0·1 per cent and even more of this substance, and yet which yield a metal very suitable for rails.

As to sulphur, while Mr Bessemer regards 0·1 per cent, as in the case of the phosphorus, as the extreme limit, according to Herr Tunner the proportion of 0·2 per cent even is admissible, at least for the Styrian pig; and trials made with Turrach pig confirm this opinion. The analysis of a Dowlais rail has shown 0·1 per cent of sulphur; but it contains only a trace of phosphorus.

The inferiority of the converter, compared with the puddling furnace, as regards the elimination of injurious substances, is an important matter; especially in the rail manufacture, for which ordinary pig should be sufficient. It will not therefore be out of place to dwell briefly on the causes of this inferiority. Herr Bruno Kerl remarks (*), that if the phosphorus passed into the slag in the state of phosphates of iron and of manganese, these salts would be decomposed by the metallic iron under the influence of the high temperature developed in the converter; so that the phosphorus would return to the metal. The same is the case with the sulphur, the sulpho-silicates in which it was present being also decomposed by the iron.

" The silicious nature of the slag," says M. Grüner, " explains why the phosphorus cannot be eliminated by the Bessemer process; while it is eliminated in puddling and refining in the reverbatory furnace. In order that the phosphoric acid may be retained by the bases, it is necessary that the slag be basic and not silicious (**). "

This being the case, would it not be possible to give to the slag by the addition of some suitable substance, lime no doubt, the basic nature which is wanting?

This question, being one quite special to metallurgy, the author has submitted it to his colleague M. Grüner, and he cannot do better than transcribe here the reply which he owes to the kindness of that skilful metallurgist.

(*) " Handbuch der Metallurgischen Huttenkunde ", vol. III, p. 659. — Arthur Félix, Leipzig, 1864.
(**) " De l'acier et de sa fabrication ", p. 253.

Paris, April 26, 1868.

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" Berthier has long ago proved, that phosphate of iron is decomposed at a high " temperature by metallic iron. Now, in the Bessemer converter, where the temper- " ature is very high and the mixture of substances very intimate, this reaction must " infallibly take place. A portion of the phosphate would, however, escape the action " of the iron if the slag was very basic; but you have been able to see by the ana- " lyses which I quote that this effect is not produced (or rather does not commence), " until after the complete expulsion of the carbon : up to that point the oxide of iron " is continually reduced by the carbon and the silicon; and, when these two ele- " ments have disappeared, the oxide of iron attacks the sides of the converter and " corrodes them rapidly. There is, therefore, always some slag more or less sili- " cious, which does not retain the phosphoric acid.

" It is otherwise with the puddling furnace, especially in cold puddling; in the " first place the mixture is much less intimate, and the temperature lower, so " that the reaction of the iron on the phosphate is much less energetic; then, and " this is the principal reason, the sides and the bottom of the furnace are of cast iron " coated with oxide of iron and not formed of bricks. As long as puddling was car- " ried on with sand bottoms, the expulsion of the phosphorus was impossible; the " slag was always silicious. At the present day, with the floor cooled, and with cast " iron sides (with a current of air or water), basic slag may be obtained, which " becomes charged with phosphoric acid.

" Additions of lime would probably be more energetic than additions of iron ore " and of manganese (tried unsuccessfully by Mr Bessemer); but the phosphate of lime " is also decomposed (partially at least) by the iron, at a high temperature, so that " I have no great hopes even of this reagent. Besides, lime was formerly tried in " the Styrian process; it produces a partial purification, but the slag becomes " more pasty. This last-named effect need not be dreaded in the Bessemer " apparatus on account of the high temperature; but the corrosion of the sides, and " the decomposition of the phosphorus by the iron must always be feared.

" I should prefer to try lime in the Martin furnace (364), and I think that in this " case a more favourable result must ensue. With successive skimmings, and also " successive additions of lime, the elimination, at least partially, of the phosphorus " ought certainly to be achieved. "

It is well known that manganese is injurious to steel, that it makes it short. If then, as experience proves, the presence of a certain proportion of this metal in the principal pig be useful, it is only as auxiliary to the operation. Becoming oxidised before the carbon, it retards the refining. Besides it renders the slag more fluid and more easy to separate, and diminishes the amount precipitated. In the interesting paper quoted above (*), M. de Cizancourt gives an instance of charcoal pig from Follonica (Tuscany), the treatment of

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(*) " Annales des Mines ", vol. IX, 1863, p. 225.

which in the converter was much more regular, on the addition to the bath of a certain proportion of very poor manganese ore. It is well known, besides, that, in puddling for steel, oxide of manganese is often added at the moment of boiling; the slag, thus rendered more fluid, is easily got rid of under the hammer.

364. *New processes on trial.* — M. Bessemer, while studying the applications of his grand and fruitful conception with a perseverance worthy of it — and this is saying much — has for a long time been endeavouring to render the converter capable of treating ordinary pig irons; the preliminary operation to which he subjects them is, in principle, a kind of puddling combined with the injection of various gases, and the use of several reagents. We cannot, however, here deal with experiments, which have not yet lead to practical results.

By obtaining, in a state of fusion, a product more or less completely refined, Mr Bessemer has opened a way which other inventors seek, like him, to enlarge still further; by dispensing with the onerous condition of purity in the pig dealt with. They almost always revert to the same thing as puddling, but to a very energetic puddling, kept up until the iron becomes fluid, and not merely viscous as in the ordinary operation; and continued for a sufficient time for the more or less complete oxidation of the phosphorus and of the sulphur by the oxygen in the slag.

Mr Nystron, of the Gloucester works near Philadelphia, confines himself to allowing the blast to play upon the surface of the molten metal.

Mr Richardson forces air into the bath, and in this respect approaches the conditions of the Bessemer process, while at the same time preserving the comparative superiority of puddling for the partial elimination of the phosphorus.

M. Bérard operates in a Siemens furnace, and first directs into the pig an oxidising current, then a current of hydrocarbonized gases for the purpose of eliminating, by their hydrogen, the sulphur and the phosphorus; but the success of the experiments made at Montataire (Oise) would appear to be but slight.

The Siemens-Martin process is also founded on the use of the Siemens regenerative furnace, that valuable appliance for producing high temperatures and regulating reactions by the composition of the flame. Cast iron, previously raised to a red heat in a supplementary furnace, to which wrought iron is subsequently added, are charged in together as in the crucible. Stirring is not very practicable, at least by means of iron paddles, which

melt almost immediately; nor is it necessary. At Firminy (Loire), the operation is carried on with a mixture of cast and wrought iron only. The bottom of the furnace, formed of a mixture in equal parts of aluminous and magnesian sand obtained from casting moulds and from the same sand raw, stands tolerably well. It should be repaired after each operation; but it is only thoroughly renewed, they say, after every three weeks' working. It is cooled on the outside by a jet of steam, which causes, like the exhaust of the locomotive, a continuous current of air. The progress of the operation is ascertained by means of samples taken out by a kind of spoon, which are cooled and broken to show the grain. Thus a test is afforded for the addition of the special pig, which is made as in the Bessemer process. The slowness of the operation, lasting from eight to ten hours, allows of a more or less prolonged testing, and permits of the resulting metal being more easily graduated than does the Bessemer process; thus, pig is often added at several intervals. But, notwithstanding the state of fluidity of the substance, complete homogeneity is not obtained, this quality being often wanting even in a test piece. This is easily explained: the energetic stirring that takes place in the Bessemer apparatus, by the injection of air, is here completely wanting.

Hitherto M. Martin has, at Firminy, only used pig of superior quality, obtained from Mokta-el-Hadid. Is the operation more suitable, as has been said, by the very fact of its duration, than the Bessemer process, for eliminating extraneous substances? No positive result has as yet confirmed this supposition. It is, besides, natural to operate first with selected pig, so as to avoid from the commencement, increasing the difficulties.

M. Fabré, engineer of the fixed stock on the Mediterranean Railway, says, "Trials "at the works only have been made on Martin steel rails, which place them in the "same rank with the Bessemer rails, and even above them. They appear to have "greater rigidity and hardness. Their resistance to impact and pressure is, besides, "very satisfactory. The rolling seems more difficult of accomplishment, and the "making of the ingots a more laborious operation. I think that, on these two "accounts, the price will be much higher than that of Bessemer rails."

This opinion would seem to consider, that the Martin steel made at Firminy, is more highly carburetted than Bessemer metal tried by actual service on the line.

It would, however, be premature to decide as to a process which borrows from the Siemens regenerative furnace its only real character of novelty, and which is still in a state of trial. One can only await the result of the experiments which M. Martin is conducting at Sireuil. According to this engineer, the reverberatory furnace by this process yields methodically four distinct products,

having their special applications: 1st cast steel; 2nd cast iron; 3rd homogeneous metal; 4th mixed metal (malleable cast iron). This process is interesting to railway companies chiefly as regards the treatment of old rails, to which it seems well adapted. According to M. Martin, rails may constitute two-thirds of the charge; provided, no doubt, that they be exempt from phosphorus and from sulphur.

Mr Parry has made numerous experiments at Ebbw-Vale to further the use of impure pig, and especially phosphorous and sulphurous pigs, for treatment by the Bessemer process. The method which he has determined upon comprises two preliminary operations: — 1st ordinary puddling, which purifies the metal by the action of the basic slag (363); 2nd a recarbonization by remelting in the cupola with a large excess of coke. It needs very cheap pig iron, and complete success, to allow of so complicated a process being carried on commercially. There is, besides, a difficulty: if the puddling lowers the proportion of phosphorus to an admissible extent, it also eliminates the silicon, so that the pig does not contain enough of that substance to pass into the converter. It becomes then necessary to restore some to it by the addition of a highly silicious special pig. In fine, if the process is possible financially, it is so, doubtless, only in special cases which rarely occur.

A like conclusion was the result of experiments, made at the Royal iron works at Königshütte (Prussia), on pig containing as much as 0·497 per cent of phosphorus. Without absolutely condemning the Parry process, the conclusion arrived at in consequence of these experiments is, that, under conditions like those of the Königshütte establishment, the use of the native pig with the previous application of this process can never compete with the direct treatment by the converter of special pig, notwithstanding its higher price.

365. The Cleveland oolitic ore produces a pig much too highly charged with phosphorus to be treated in the converter. The ironmasters of that district are making great efforts to surmount this obstacle; and to obtain, by other means, a refined cast metal. Some samples have stood ordinary tests successfully; but at present there have only been some mere trials of a process which is, besides, kept secret.

366. The experience, so favourable, of Bessemer rails has been a source of disquietude to ironmasters, thus threatened in one of their principal markets. If it were only a question of substituting, either wholly or in part, the converter for the puddling furnace, this would only amount to

one of those changes of plant to which the trade is subjected by the very fact of its progress. But such is not the case with the several works which depend upon ordinary ores, producing impure pig; which the new methods have not yet succeeded in converting into a cast metal capable of being rolled.

Doubtless, the development of means of communication, and the lowering of the tarifs both of railways and canals, would permit of rich and pure ores being carried long distances without their price being raised too highly by cost of transport. It is due to this widely spread transport of choice ores that many works, employing the ordinary processes, have been able to improve in a remarkable degree the quality of their products. But a cost price, though admissible for ores intended merely to improve the bath, into which they enter in only a slight proportion, would often be impossible when these ores must be, on the contrary, the principal element; the cheap ores being admitted only in a small proportion.

On the other hand, indeed, it is precisely the special nature and the comparative rarity of those ores suitable for yielding, either by the converter or the reverberatory furnace, the refined cast metal, which limits the production of this metal, and permits ordinary iron to compete with it in the railway market.

The chances of fresh reductions in price (348) are often looked forward to in favour of Bessemer metal; independently of those caused by the expiration of the principal patent. Others affirm, on the contrary, that a rise in the price of steel is more probable, and the greater, the more complete its success; as the cause of the alleged fall would be more than compensated by the inevitable increase in price of special ores. If the railway system was complete, and it was only a question of renewal of the permanent way, the quantity of new material to be produced yearly would be inconsiderable; as the actual consumption, already slight for iron, would be necessarily much less for steel. But who can foresee where the extension of railways will stop?

Conjectures on such a subject are very hazardous; but that a certain degree of probability lies in the second opinion, as to an increase of price, cannot be gainsaid. Bessemer metal has against it, however, from a commercial point of view, only this condition of the special quality of the ores; and which it may perhaps succeed in overcoming. As to the cost of plant, if it be considerable, this drawback is amply compensated by one valuable property of the apparatus : its power of production.

The success of the Bessemer rail is so remarkable, that it leaves little ground for criticism, though it be whetted by threatened personal interest : even

so, rare and timid has been the criticism. It has indeed been stated (*) "that the iron rail, manufactured with the care formerly bestowed upon it, but which has since been discontinued, may compete successfully with the Bessemer rail." This is easy to say, but difficult to prove. Let the endeavour be made, however; all the better. If the competition of the iron rail, against the redoubtable rival which threatens, at least partially, to supplant it, leads to its quality being improved, this would be one more service rendered to railway companies by Mr Bessemer's discovery.

(*) See "The Engineer" of 1866.

CHAPTER XII.

DRAINAGE OF THE LINE. — AMELIORATION OF CUTTINGS AND EMBANKMENTS.

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§ I. — Drainage of the surface-way.

287. *Lateral drains.*— We have already urged (174) the importance of the drainage of the line. It is necessary to enter into some details of the means by which this can be best effected. The drainage of the slopes, that is to say, the condition, which in many cases is a *sine qua non* for the stability of the earthworks, both cuttings and embankments, depends most closely upon that of the surface-way; it is natural therefore to treat these two subjects in the same chapter.

According to the conditions of art. 7 of the French government specification:

" The Company is required to place along the side of the railway, the drains which " shall be considered necessary for the drainage of the way and for the discharge " of the water. The dimensions of these drains shall be determined by the author- " ities, according to local circumstances, and upon the propositions of the company. "

In Germany, the instructions of the Dresden meeting recommend, that the level of the water be lowered in such a way, so as not, even at its maximum height, to be affected by frost (*).

The ballast should, as far as possible, be perfectly permeable. The outflow therefrom taking place at the formation level; the cross sectional surface of which should have an inclination outwards of about $\frac{3}{8}$ of an inch per foot.

But this permeable condition is often not attained; in which case infiltration alone cannot be reckoned upon, and a surface flow must be allowed, which can be facilitated by giving to the ballast slight longitudinal inclinations towards the cross drainage-grips.

The slope given to the side drains is generally about the same as that of the formation level surface, as described above; the width of the bottom of these drains should be about 14 inches (Plate XXXIII, figs. 1 to 5). The

(*) " Vereinbarungen, etc. ", art. 33.

depth and the width at top varying according to the gradient, and with the volume of water to be discharged. Its sectional area should be considerable in long and deep cuttings, and on level portions where the side slopes are easy. Especially, if in addition to the water from the higher part of the line, and to that which the cutting receives directly, there occur on the face of the slopes alternate layers of permeable and impermeable strata. Sometimes, owing to the absorbant nature of the subsoil, the section of the drains may be diminished, a portion of the water soaking through the bottom. An instance of this may be cited in the Clamart cutting on the Paris and Rennes line, cut through calcareous eocene strata; perforations are made through this to discharge the water into the chalk below, which absorbs it.

The French government specification (art. 7) requires a bench at least twenty inches wide to be left at the foot of the ballast slope. This space, useful for the protection of the drains, forming a provisional deposit for the refuse while they are being cleaned out, and also a pathway along the line, was formerly placed at the foot of the slope of the cutting; but, as it was found soon to disappear in that position by the action of the water, and from slips, it has been removed to the opposite side of the drain (figs. 3 to 5).

On many of the German Railways, the ballast is deposited in longitudinal trenches cut below the formation; at which level narrow paths are left, and through these, at intervals a narrow channel is cut at right angles, for the purpose of discharging the water from the ballast into the side drains. But, though this arrangement reduces the cube of the ballast, it is attended with several disadvantages. The ballast is wasted by its mixture with earth, the maintenance is rendered more difficult, the drainage is less perfect, and the saving is after all but small; besides, at the present time, this "Koffersystem" is but little used.

The top width of the drains in cuttings may be reduced by the adoption of a dwarf wall, when the cutting is through rock, on the side next the line, or likewise at the foot of the slopes. These dwarf walls M, M, (fig. 6), render the clearing of the drains a little more difficult; they are sometimes constructed with rough stones, sometimes with stones on a bed of mortar; they are carried up to about the level of the ballast, and thus replace the required bench, the width of which is reduced to 16 or even 12 inches. They prevent the ballast being carried away by the action of the water in the drains, but their principal advantages are the reduction of the width of the cutting at its base, and a saving in the cube of the cutting, proportional to its depth. It is generally when the depth exceeds from 20 feet to 25 feet, that their use becomes economical. It is almost unnecessary to add, that weeping holes should be arranged at certain distances towards the base of these walls so

as to allow a free passage of the drainage water from the formation level into the lateral drains.

In tunnels, drains are often superseded by one or two masonry channels *c*, *c*, at the foot of the side walls (Pl. XXXV, figs. 2 and 3), or by a culvert running longitudinally under the centre of the tunnel. In the Ivry tunnel of the Paris Suburban Railway, these side channels have, notwithstanding the gradient of 1 in 100, a considerable area; being 18″ wide at the top, 12″ at the bottom, and with a depth of 2′.9″. The dwarf wall, that keeps the ballast in its place, is 12″ thick at the top and 18″ at the bottom. Where tunnels are perfectly dry, and there is no water to flow through them from the higher part of the line, neither channels nor culverts are necessary.

268. *Drainage of the formation surface.* — Lateral drains are often found insufficient to drain completely the line in a cutting; recourse is then had to a more perfect system of drainage. The Eastern of France Railway Company has carried this out on a very large scale; a few examples of their applications may be cited.

1° *The Montegu Cutting.* — Paris and Strasburg line. Length of drainage 260 yards. A circular drain pipe, $2\frac{1}{4}''$ inside diameter, is placed in the centre of the six foot way, 2′.8″ below the level of the rails; it has the same fall as the rails, and discharges on to the invert of a culvert. The trench, in which is laid this drain pipe, was 14″ wide at the bottom and 2′.0″ wide at the top; after placing the drain pipe in position, this was filled in with stones of various sizes, upon which was placed a covering of moss from $\frac{3}{4}''$ to $1\frac{1}{4}''$ thick, upon which the ballast rests. This work was carried out in the course of 1863, at a fixed price of $2^s/4^d$ per yard run; and so far, it has cost nothing for repairs or maintenance. The results have been most satisfactory. Before this system of drainage, was introduced, the clay, which forms the subsoil of the bottom of this cutting, mixed with the ballast, unsettling the permanent way and at the same time rendering its maintenance difficult; at present its condition is like that of other cuttings.

The *Laneuville* cutting, on the same line, has been drained for a length of 330 yards. The circular drain pipe, $2\frac{1}{4}''$ diameter, is placed at a depth of about of 3′.3″ to 3′.6″, with an inclination of 1 in 250; it discharges into an open drain. This work, carried out at the same time and at a similar price as the last mentioned, has given equally satisfactory results.

The *Saint-Phlin* cutting, also on the same line, has been drained in two portions, one of a length of 480 yards, the other of 460 yards. Two drain pipes, of $2\frac{1}{4}''$ interior diameter, laid side by side at a depth of 3′.8″ to 4′.0″ with an

inclination of 1 in 270, discharge from each portion into a culvert. This work, executed under the direct supervision of the authorities cost, 2s/ per yard run; completed in 1861, it has since required no repairs. Its efficiency has been even more remarkable than in the two previous cases, owing to the greater difficulties which existed.

" Before it was carried out", says M. Varroy, the engineer, in charge of the works, " it was almost impossible to keep the permanent way in an efficient state. " After a day's rain or after a storm, the clayey subsoil got softened and mixed up " with the ballast; nothing of the kind now takes place, for the permanent way is in " an efficient state and is easily maintained. "

The *Marainviller* cutting has been treated in the same way for a length of 720 yards; of which 220 yards were laid with a single line, and 500 with a double line of pipes, placed at an inclination of 1 in 300, and sunk to a depth of 3 feet below the rails. The average cost of this work was 2s/ per yard run. The condition of the line has been much improved by this work.

§ II. — Settlement and drainage of the slopes of cuttings.

369. It is hardly necessary to state, that the several types of cutting-slopes, shown in figs. 3 to 6 of Plate XXXIII, cannot be taken as absolute.

Thus, in cuttings of ordinary earth or of chalk, the 1 to 1 slopes of sections 3, 5 and 6 become $1\frac{1}{4}$ to 1. In wet clayey soils the $1\frac{1}{2}$ to 1 of section N° 4 may be altered to 2 to 1 and even more. On the other hand with firm strata this may be reduced, to even to $\frac{1}{5}$ for the lower portion of the slope in figs. 5 and 6. These types are, in fact, but averages; to be departed from more or less as required after an examination of the special conditions of each case. It is, however, important not to risk any considerable slips in the slopes, which may become costly and entail great inconvenience in the after working of the line. The belt of land outside ought to be such as to meet all emergencies; for the acquisition of any additional quantity required for the above purpose might be a matter of some difficulty, and a wish to economise under such circumstances may have quite a contrary effect.

370. The causes which are injurious to the slopes of cuttings and embankments are, either only exterior, or both exterior and interior. The last, which are the most serious, are always caused by the presence of water and generally also by that of clay. Clay is also the cause of inequalities in the surface of the slopes. When, however it is only a matter of protecting the slopes

against atmospheric influences, this may be done without much difficulty and at little expense.

Quicksand is often, of all soils, the most difficult to confine. M. Bruere (*), as a temporary means, has successfully made use of fascines filled with gravel, which are rapidly deposited by experienced workmen against the running sand; and other definitive means of consolidation and drainage can afterwards be applied.

In rock, the slopes and the cuttings may require a certain amount of protection, even if the stone be sound, but liable to the action of frost; here a simple facing will suffice, enough apertures or "weeping-holes" being made in the wall for the discharge of the water, which may accumulate behind it. But, if the rock contains fissures and dislocations, slips may be expected; especially if there occur many veins and pockets filled with clay. Even granite, porphyry, and generally all felspathic rocks, are far from being free from this danger; it often happens that blocks, of more or less volume, are often separated from one another by clay, formed by the decomposition of the rock itself. Clayey schists should be carefully watched especially, if their sliding surfaces be much inclined towards the cutting. Besides, as they are frequently cracked and decomposed, the action of the water which enters these fissures then becomes very injurious; it often happens that, in cuttings of schist where the slope is insufficient, much has to be removed, before the rock can be made to stand.

In mobile soils the top of the cutting is often protected by an outside drain, constructed only on the upper side, when the cutting runs through inclined ground; by this means, the water is intercepted before reaching the cutting, and its injurious action on the slopes prevented; this drain may either discharge outside of, or at the end of the cutting, into a brick channel down the slope itself. M. Bruere may be going rather too far (**) in his entire objection to these intercepting drains; he wisely, however, puts engineers on their guard against the dangers these drains present, when not perfectly watertight. In permeable soils, a slight inclination of 1 in 5, falling from the cutting (Pl. XXXIII, figs. 3 to 6) is to be preferred; while intercepting drains, as described above, may be used without danger in clayey soils, but even then should not be nearer than 3 feet to the upper edge of the cutting (fig. 4).

Even with the same ratio of height and width of slope, the exact inclin-

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(*) "De la consolidation des talus", 1862. This little work, the result of long practice, contains much useful information.

(**) Work just referred to, p. 44.

ation depends on the use, or not, of a side bench, which is useful in preventing crumbling earth from entering the drain and obstructing the flow of water; for this reason these benches are slightly inclined towards the slope. The drained water is carried through brick channels down the face of the slopes into the drains. Besides, the conditions, as to when they may be adopted are not very clearly defined; engineers, both those who make use of them, as well as those who reject them, do not appear to do so from any definite reasons.

371. *Sowing, planting, sodding, and pitching of slopes.*— Vegetation not only consolidates the earthwork of the slopes, but also weakens the action of the water, which it spreads out and thereby diminishes its velocity. Grass seeds require for a slight depth a made up soil, and consequently less inclination than the slope itself. Clover and dog-grass, with their deep spreading roots are the best, but the soil is not always suitable to them; trefoil in such cases may sometimes be used, although not with the same amount of success. Young trees do not require a made up soil, and allow of steeper slopes; but they do not afford an equal protection. Near to pasture lands, sodding is often economical; the sods should not however be merely laid flat on the surface, which adds but little to the stability, but be placed in layers at right angles to the slopes, which gives much better results.

Pitching, or facing with dry stones, has often been made use of; it is however costly, and many engineers dispute its utility.

" Generally ", says M. *Ledru*, " their utility is very limited; and even, when they " rest simply upon the natural soil without any means of internal drainage, they are " more dangerous than useful, because they retain between their joints the water " which softens the soil upon which they rest. They may nearly always be advan- " tageously replaced by a sodded slope of good soil. "

Dry-rubble arches, of pointed form, are sometimes employed, embedded their entire depth in the slopes, to which they act as supports; but they get easily displaced.

Arches in masonry, superposed on one another, are also sometimes made use of; an example of this description of consolidation is to be found on the railway from Bologna to Pistoïa, one of the most remarkable lines in Europe, from the boldness in the selected course of the line, as well as from the importance, the variety, and the difficulties of the works of art, carried out with great ability by Sig^r Protche. The slopes of the cutting called *del Ladro*, opened in the hill side in the valley of the Reno, has been supplied with two stages of semi-circular arches, of 13 feet span, the piers being one above the other

(Plate XXXV, fig. 20) : the embayments *b*, *b*, *b*, between the arches are faced with dry stones.

372. Very thick retaining walls, connected by an invert under the railway, are at times quite unequal to resist the enormous pressure of very compact or of highly water-bearing strata. This was the case in the cutting outside the Charonne tunnel on the Paris Suburban R^{y}; where it was found necessary, when the retaining walls had failed, to extend the arching of the tunnel. In similar cases, where the causes of internal destruction have to be combated, it is the cause itself that should be attacked; and not the consequences thereof, which are often irresistible.

373. *Process adopted by M. de Sazilly.* — A very frequent cause of slips in slopes, is to be found in the presence of bands of clay situated between layers of porous strata. Their action has been examined with much care by M. de Sazilly, and he has deduced, after careful observations, a process of amelioration; which is in reality but a form of surface drainage. A layer of clay, covered merely with porous soil, retains the water which reaches it by direct filtration. If there should happen to be above it other clay belts placed between permeable strata, it receives both the water which passes from the intercepted impermeable layers above it, as also that which finds its way through the outcrop of the superincumbent permeable layer. The slopes of a cutting in such a case present a series of superposed beds of exudation. This exudation, acting upon the intercepted bed of clay causes it to crumble away by degrees; the superposed permeable bed then overhangs somewhat, and in it turn its slips away. It is especially after a thaw that this takes place, most seriously. During a frost, the frozen water at the face of the exuding layer forms a kind of impervious barrier, which stops the outflow. While this is taking place, the water inside accumulates, and, on the removal of the obstruction by a thaw, proves most destructive : partial slips begin to show themselves, soon ending in others of much greater magnitude. M. Bruere disputes this special influence of frost; its effect is however clearly established. It is especially to frost, that are due the injurious results produced upon the exuding strata, which under ordinary circumstances yield but a very limited quantity of water. The action ot drought, during which the clay shrinks and cracks, further predisposes it to the injurious effects of water, as soon as it comes in contact with it.

M. de Sazilly from a consideration of the above facts deduces the following conclusions; that the intercepted bands of clay should be protected both from

the action of heat and of water, and also that the free discharge of water during a frost should be ensured. A channel R, R (Plate XXXV, fig. 23) following exactly the undulations of the exuding strata, is bottomed with bricks *b*, *b*, *b*, laid in mortar, its interior edge, level with the upper part of the layer of clay, receives the water that flows from it; it is filled with broken stones, and in order to prevent any obstruction, the stones are covered with sods placed the grass downwards : but, if the latter be too expensive it may be replaced, as was done by M. Bruere, by coarse mats. The entire surface of the slopes is covered with a coating of well rammed vegetable soil T, T, 10″ to 20″ thick, measured at right angles to the slope; occasional benches connect this coating with the body of the cutting. At each point of depression the channel empties itself laterally, the water being carried to the lower drain by a channel following the steepest inclination of the slopes, and formed according to circumstances, either of stones, of turf, or of tarred planks.

374. ***Drainage of the slopes.***—Although M. de Sazilly's system may have afforded very good results, yet ordinary drainage, as usually understood, by means of drain pipes is at the present time generally preferred to it. It was indeed but natural to extend to the slopes, the same method which had been successfully applied at the formation-level (368). Drain pipes are also less liable to displacement and to disconnection than are the channels of M. de Sazilly. He seems, naturally enough, to have ascribed too general utility to his own process; by unduly generalizing those exterior and only superficial actions, the effects which he had specially studied. A drainage, which is easily carried out at a certain depth, and which ameliorates a crust, so to speak, of a considerable thickness, is an intermediate solution between M. de Sazilly's process, which acts on the surface (*), and those methods recurred to when the water must be collected from the mass itself; thereby augmenting the thickness of the crust drained, and consolidated.

Much attention has been paid to drainage of the slopes on the Eastern of France R^y, as also to that of the formation-surface. Secondary drains of $1\frac{1}{2}''$ to $1\frac{3}{4}''$ diameter, placed, at different depths of from 16″ to 32″, down the greatest inclination of the slopes, lead into others of $2\frac{1}{4}''$ diameter, running along the foot of the slope parallel with the rails, and which finally discharge into the lateral drains. In the *Virecourt* cutting, on the Blainville and Epinal line, a length of 210 yards of secondary pipes, and 308 yards of collecting drains,

(*) It is hardly suited for any depth, in consequence of the care it requires.

clears the water off 3000 square yards of slope surface. In the *Sourburg* cutting, on the Strasburg and Wissemburg line, 1300 superficial yards of slope-surface are drained by a length of 306 yards of secondary pipes, and 590 of collecting drains. The mean cost per yard run, everything included, has been 1s/8d. The slopes of this Sourburg cutting, which were formerly irregular, furrowed by the water, and with slips in places, have stood well since the completion of the works in 1862.

This successful result determined the Company, in 1863 and 1864, to make use of the same mode of drainage in a very large cutting, where the means first applied had been without success; namely the *Loxeville* cutting on the Paris and Strasburg line. It is desirable here to explain a few of the details of this work, which is of considerable interest from its importance and success (Pl. XXXIV).

The Loxeville cutting is 1600 yards long, and at certain points is as much as 56 feet deep; it is cut through, 1° a layer of vegetable earth, of variable though never great thickness; 2° a bed of calcareous strata 16ft to 20ft thick, exceedingly porous, and containing pockets 13ft to 16ft deep, in which water accumulated; and 3° a very compact clay, which wasted away under the action of the air. From the very beginning the engineers in charge of the work found it necessary to take means to prevent slips. The means then adopted consisted of a continuous series of shallow excavations filled in with rubblework on the entire surface of the slope, in the form of a double row of gothic arches, 6ft.6ins. apart, and 16ft.6ins. in length; the piers of the upper tier resting of the crown of the arches beneath (figs. 1 to 4).

This arrangement answered satisfactorily for several years; but, in course of time, although as a whole it stood well, slips took place at several places, and threatened to increase. It was therefore deemed advisable to adopt as precautions the following operations : 1st preparatory works, and 2ndly drainage. The preparatory works consisted of:

1° Cleansing and reinstating the open drains at the top of the cutting, at the steps, and at the base, for a total length of 9,300 yards (see figs. 1, and 5 to 25); the last named drains were, moreover, faced with dry rubble stones to keep the ballast in its place.

2° A masonry drain and dry rubble benching 76 yards long, above the slip F, a very heavy one (figs. 1, 3, and 14 to 17); to prevent the water in the upper drain from filtering down into the slope.

3° A masonry overfall in the left-hand slope of the cutting, in order to convey into the drain at the foot of this slope, the overflowing waters from the drain

of the first step; which had, on several previous occasions accumulated at this point, and had produced heavy slips.

4° The reparation of the arch-like rubble work on the surface of the slopes, which had not been quite destroyed. Those portions that had been destroyed were not rebuilt.

5° The removal of the earth from the slips, consisting in great part of laminated clay forming the subsoil, and amounting to 7,850 yards cube.

When this was done, the drainage of the slopes was carried out on the principle now generally adopted by the company.

Cross drains, of an inside diameter of $1\frac{3}{4}''$, from 6'.6" to 10'.0" apart, according to the estimated volume of water to be removed, were placed at a depth of about 3'. 3" or 4'. 0"; and were covered with a layer between 12" and 16" thick of broken stones, which could pass through a ring of 4" to 6" diameter, upon which was placed a bed of moss. The trench was then filled in with successive layers of vegetable soil, every eight inches in thickness being well punned; and the whole finally covered with well rammed sods. The plan, elevations, and cross sections, shown in Pl. XXXIV, illustrate the general arrangement.

The $2\frac{1}{2}''$ collecting pipes discharge into the drains at the foot of the slopes; their ends being curved to a radius of about 6'.6" (fig. 1 to 3). The last length of drain pipe is placed in an aperture made of two large blocks of rough stone, the lower one forming a basin; and which can both be easily removed to inspect and cleanse the drain.

COST :

	£ s d
Repairing and draining a surface 6,817 yards as described.	
At about 1s/0d. per yard sup. say.	360·0·0
Cleansing and construction of open drains, stone walls and sluice, and putting in proper repair 130 arches.	120·0·0
Removal of 7,850 cubic yards of earth from slips.	60·0·0
Equal to a total of about 1s/7d. per yard sup[t].	540·0·0

375. — The drainage of the bottom of a cutting and of its slopes, carried out as explained above, is generally successful; although in some cases it is not sufficient. The nature of the soil and the abundance of water compel, at times, a deeper system of drainage. It then becomes necessary to operate much lower, in order to draw the water from the heart of the slopes.

The *Dockenberg* cutting, between Altkirch and Dannemarie on the Paris and Mulhousen line, presents a remarkable instance of these difficult cases, and of the comparatively simple and economical means by which they can be overcome (Plate XXXIII, figs. 7 to 15).

This cutting runs through a formation composed of sand, clay, and permeable marl, resting on a bed of nearly pure sand, and which overlies an impermeable marl. Slips having taken place, as might be expected, it was found necessary to adopt the following improvements.

1° An upper drainage (figs. 7, 9, and 10), which extends on one side the entire length of the top of the cutting; discharging at one end its main body of water into a small stream, and at the other into the central collector of the lower drain, as mentioned hereafter.

2° Towards the middle of the cutting, a length of 260 feet, often liable to slips, and at a depth of about 5'. 3" below the formation-level, was divided into 14 distinct compartments by detached inverts, which are connected with one another at either side by horizontal arches (figs. 7 and 11).

3° A system of cross drifts, forming the special mode of drainage in this case, opening towards the bottom of the slope, a little above the line of separation between the sand and the impermeable marl, and dipping towards the line. These drifts, figs. 7 and 8, are 2'.6" wide by 4'.6" deep, and are 33 feet apart; they are driven more or less into the waterbearing strata according to circumstances, and the quantity of water; their average length is 33 feet. From the lower end longitudinal spurs are thrown out, which are united together in those parts where the water is most abundant; thus forming at each side a longitudinal gallery of about 270 yards in length. The bottom of these subterraneous ways is covered with a layer of gravel 10 inches thick, which forms a bed, in the cross galleries, to receive two 4" pipes. These pipes, the joints of which are covered with moss, are covered with a fresh bed of gravel, and the remaining portion of the trench is then filled in with dry stones. The cross drains discharge into a collector, consisting of 12" pipes placed in a longitudinal trench 7'. 3" deep below the level of the rails, and running along the centre of the cutting. The main drain discharges into the stream, with a volume of between 130 and 150 gallons per minute, even in dry seasons.

376. If what is termed "Drainage" as applied to cuttings is of recent date, the same cannot be said of "Dry pitching" as applied to their faces. M. Séguin aîné gives a remarkable example of its application, by means of which he obtained a perfect remedy for a cutting which was before this continually liable to slips.

"During the dry season I had caused to be excavated", he remarks, "a trench ten "feet deep at the foot of the slope; of which the space B C (Plate XXXV, fig. 24) was "filled with stones placed by hand, and afterwards covered from C to A, with clay,

" in order to prevent the water of the side drain from depositing in the interstices " between the stones the earthy matter conveyed by it (*). "

377. *Trenches or galleries, at the higher end of a cutting, affected by a sliding formation.* — A means at times adopted, to prevent soils having a tendency to slide upon an inclined bed of clay and dipping towards the cutting, consists in opening at the upper end of the cutting trenches or longitudinal drifts to receive the water; by which means a large mass of earth is drained so as to form a sort of abutment to resist the thrust of that, which is impregnated with water. For instance, this plan has been applied to the cutting at ***Grosslochgraben*** on the Baden R^y, cut through inclined ground, of a clayey-calcareous conglomerate, which sometimes became converted into a perfect pulp. In case of emergency, the cutting might have been opened out; but it soon began to fall in again, while the land slips were felt at a considerable distance off. In the first place, it was thought desirable to excavate as far as the moveable earth extended itself, while the extra depth, varying between 12'.0" and 15'.0" was made good with broken stones. But, notwithstanding this costly work and the construction of an enormous retaining wall at the foot of the slope, troublesome slips soon began to show themselves; and it was found necessary to resort to means, which, had they been adopted in the beginning, would no doubt have succeeded; namely, the construction of a drift which drained off the water from the top side of the cutting. — The same principle of drainage has been carried out at the ***Greppo*** cutting, on the Pistoïa line, where, after it was completed, slips began to show themselves, extending back a length of 160 yards beyond the top line of the slope. These, however, were stopped by running a drift G, G, at a depth of 66 feet, with several spurs at right angles A,A, (Pl. XXXV, fig. 21). The drifts were well shored up with timber, as also were the small shafts P, P, and then lined with stone.

It is not necessary further to dwell upon this process, which is very reasonable, but costly, when it is found requisite to go to any great depth. If, however, its application is found to be absolutely necessary, it is better to recognize the fact at once, as soon as the cutting is excavated; and so to apply it before any real disturbance takes place, instead of tardily reaching it after a variety of useless experiments. The ability of an engineer lies as much in accepting resolutely that which is indispensable, as in avoiding that which is superfluous. It is well known, that it is difficult to re-establish the equi-

(*) " Des chemins de fer, de l'art de les tracer et de les construire ", 1839. — After a lapse of thirty years, this work may still be consulted with interest and profit. Of how few, written on the same subject, can the same be said?

librium of large masses of clay, when once disturbed. It has often happened, after an expenditure of much valuable time and money, both entirely lost, that an undertaking has to be given up; and a deviation of the course of the line adopted, of greater or lesser importance.

378. Railways are sometimes affected by disturbances quite foreign to their execution, and which act upon tracts of land of large extent and of considerable thickness. The line from Lyons to Geneva, between the stations of Changy and La Plaine, offers an instance of this kind : the entire hill is gradually shifting itself, fortunately but slowly; to all appearance, moving on a clay formation, at an unknown depth, towards the Rhone.—Under such circumstances, not as yet threatening to the general safety, nothing can be done beyond prescribing a reduced speed to the trains.

§ III. — Embankments.

379. The remarks already made (369), as regards type-sections for cuttings, evidently also apply to embankments. Thus, when they are formed with the products of earth and rock cuttings, the slopes (Pl. XXXIII, figs. 1 and 2) may be 1 to 1. When above 16'.0" in height, the 2'.0" bench outside the ballast, should be made wider; at the rate of, from 1" to 2" for every 3'.0" vertical, beyond the first of 6'.0", according as to whether the embankment be composed of chalk or of clay.

Embankments are, in some respects, under more unfavourable conditions than cuttings; for the cohesion of the earth, of which they are made is destroyed, and its slow restoration is rendered more tardy by the way in which earthworks on railways are carried out. But, on the other hand, in cuttings, the soil must be taken as it is found, with all the difficulties inherent to its nature and conditions, which must be contended with; which is not the case as regards embankments, where the materials are not determined, at least not absolutely so. If the nature and condition of the products of a cutting should be of a questionable quality, they may be dispensed with, or at all events partially so; the deficiency being made up from side cutting. An examination of the circumstances of a case may sometimes, even with moderate heights, lead to a viaduct being preferred. With heights of 100 feet and over, where valleys have to be crossed, this can only be done by a viaduct. The immense cube required generally sets aside altogether the question of an embankment, even under the most favourable conditions, both as to component materials and as to solidity of foundation.

M. Bruere says:

" Even though the products of a cutting should have proved to be very wet, yet the " fact of settlement always allow soils of all kinds to be used for the formation of " embankments, whatever may be their degrees of consistency (*)."

This remark should not be too much relied upon, although it is much qualified by him in what follows :

" As the quantities of clay brought from a cutting should be very small; it therefore " follows that embankments are mostly formed of good soil."

It is also certain, if cuttings require, at times, difficult works to be executed for their consolidation and drainage, and which are unavoidable when once the course of the line is fixed, that with embankments these may be avoided; although attended at times with heavy expenses, which nevertheless in the end prove economical.

If an embankment is situated on a moveable formation, such as on clay softened by water, or on a boggy, or marshy site, the unequally loaded ground gives way under the weight, swelling up at the sides; and the embankment sinks more or less in consequence until a new state of equilibrium be restored. This settlement has to be made up, while the traffic is going on, and is all the more costly, as the proper level has to be made good with ballast. The injury is much worse when the embankment is on sidelong ground, because its tendency is to slide and displace itself, in addition to sinking. On firm ground, if the top soil be cleared off and stepped, it is sufficient to prevent slips.

However, it is not our purpose here to inquire into the works of consolidation and drainage, that a soil may require, in order to make it suitable for an embankment, such questions belong to the construction of the railway; while here, as with cuttings, we are only inquiring into the means of ensuring the stability and equilibrium of the embankments themselves; which are supposed to have been executed agreeably to the general rules of construction, and with prudence, so as to avert disasters; and while guarding only against such causes of destruction which may be met by simple and economical remedies.

380. In embankments, as in cuttings, it is the action of water on clay, that should be guarded against. An embankment of clay will stand well; but in order that it should do so, it is specially important that the clay should have been

(*) " Consolidation des talus ", p. 44.

dry when used. The use of clay, rottened either by water or by frost, produces in the first case more or less immediate slips; and in the second, a pernicious effect on the embankment, although one slowly felt, in consequence of the gentle thaw in such a large non-conducting body. In the history of railways, numerous instances occur of partial and even total destruction, more or less rapid, which have arisen from a neglect of this elementary precaution. Even clay when used dry, but unprotected from the action of either heat, frost, or rain, is liable to serious consequences; unlike clay in cuttings, it is not affected by water from the surrounding soil, but on the other hand is it much more under the influence of heavy rains. In an embankment tipped from waggons, between the lumps of clay occur large empty spaces into which water freely enters rendering the clay slippery and even fluid; the first thing therefore is to protect the body of a clay embankment by means of an isolating coating.

This isolation can never however be perfectly carried out; imperfections in the details attendant on the formation of embankments, may aggravate the consequences arising from a break in the continuity or in the impermeability of the protecting coating. Thus, although the different kinds of earths from a cutting are more or less mixed together during excavation and in its loading, nevertheless it often happens that these differences of strata in the cutting are reproduced in the embankment; a permeable layer may thus find itself inserted between two bands of clay, when very slight infiltrations will suffice to cause slips, especially if the embankment has been widened by lateral tipping. The influence of a prolonged drought, or of settlement, will suffice to create crevices in the coating, which the vibration of the passing trains increases. It therefore becomes necessary to gather together any water that may have penetrated through the coating, to prevent its entrance into the body of the embankment. The tarred wooden conduit drains of M. Bruère, filled with stones, are in such cases successfully made use of. Fig. 15, Pl. XXXV shows their application in the case of the *Largue* embankment, near to the Paris abutment of the viaduct of the same name on the Mulhousen line. A row C, C, of these wooden drains running lengthways was placed $3^{ft}. 3^{ins}$. behind the crevices, which were all the more serious, as slips had begun to show themselves a short time before towards the other end of the viaduct (361). The drains, thus forming a broken line, with slopes and counter-slopes at an inclination of 1 in 33, fig. 17, and placed at a mean depth of $1^{ft}. 10^{ins}$. below the ballast, discharge at each low point into a channel of similar construction, but with a wooden covering, and following the broken line of the slopes at a depth of 2'. 4'' below the surface.

381. If however the body of the embankment is seriously affected by infiltrations, these superficial means will not suffice to prevent slips. It often becomes necessary to have recourse at the same time both to a deep drainage and also to some means to solidify the exterior surface. The embankment, adjoining the Mulhousen abutment of the viaduct of the *Largue*, is an instance of what should be done in such a case. It had been affected at a point, where the height is nearly 50 feet, by a slip some 130 feet long, and 6′.6″. wide at the top. The double operation (Pl. XXXV, fig. 16) included, 1st two vertical filtering channels 1′.8″. wide F, F′, of dry flints, corresponding to the two levels of the slope, and intended to drain the intact portion of the embankment; the water finding an exit through the wooden channels *c*, *c*, *c*, placed about 33 feet apart; and 2ndly the formation of a well rammed mound of earth, including both the restitution of the original slope, and also of an abutting mound adjoining the slope.

The *Morcerf* embankment on the Paris and Coulommiers line was in a similar though much more dangerous condition, it has been likewise drained by the use of two tiers of longitudinal filters; drain pipes, however, were used instead of wooden conduits.

382. Drifts as in mines, may evidently be applied for drainage purposes, either for the body of the embankment, or for the surface upon which it rests; as is the case with cuttings (375). — The *Iole* embankment on the Pistoïa line is an example of this costly method, which should only be used, when all others of a more simple nature clearly fail. The means adopted for the purpose of draining the *Iole* embankment consisted of (Pl. XXXV, fig. 22), 1st a net work of drift ways, in parts shored with timber in others pitched with rough stones, 4 feet by 2ft.6ins. in the clear; 2ndly of a discharging culvert; and 3dly of lateral dwarf masonry walls by which the inclination of the slopes, at first fixed at $1\frac{1}{2}$ to 1, was reduced, and having a well rammed mound of earth at their base. It may here be observed, that the nature of this work is beyond our proposed limits.

383. Pure, fine and dry sand is at times, on account of its mobile character, a cause of instability and even of destruction to embankments. This was the case on several lines of easy construction in Hungary, but placed almost entirely on low embankments in order to be above the level of floods. The small cost of the adjacent lands has allowed of side cuttings being made at slight expense. At various points on the line these embankments composed of pure sand, were displaced by the wind, and piled up here

and there in sand hills. A very thin covering of ordinary earth would have, in the first instance, sufficed to render these embankments stable; a condition which would have increased with time.

§ IV. — Tunnels.

384. The construction of tunnels often presents great difficulties; but it scarcely ever happens that these difficulties arise only after the entire completion of the works, to the extent of even threatening their existence, and that even in well constructed tunnels which had previously shown no defective indications. Such, however, has been the case with the *Genevreuille* tunnel, near Lure, on the Paris and Mulhousen line. It affords an interesting illustration of the unforeseen difficulties against which an engineer may have to contend. This is a case which may well be referred to, for it strictly belongs to the subject matter of this chapter; as the means adopted for its relief were opposed to an evil, for some time thought to be incurable. This tunnel (Pl. XXXV, figs. 1 to 14), 680 yards long, passes at its two ends through a strata of variegated marl, and at the middle portion through gypsum (*). It was lined in the way generally adopted for moderately stiff soils; namely, with a semicircular arch resting on two vertical side walls, and without an invert (figs. 2 and 3).

It was noticed in course of time, that the bottom gradually rose, and the permanent way had to be lowered to the same extent; and the side walls soon began to crush in. The cause was easily found; the construction of the tunnel, especially of the shafts, had disturbed the channels of the subterraneous waters, diverting them into the gypsum, which, while absorbing them, had increased in bulk.

Here again it was the effect, and not the cause, that was first combated; an invert R, R, was constructed, while the thickness of the two upright side walls was increased (figs. 4 to 14); these additions, however, proved of no avail, for the invert was raised up and the walls were still crushed in. In fact it was a hopeless struggle against a force, as irresistible as that of thawing ice. Fortunately the gypsum was only affected by water to a certain depth below the level of the rails. The formation kept pressing upwards and compressing the side walls; which crumbled and split, as would a solid loaded from above and too short to bend (fig. 1). The destructive consequences would, however,

(*) Strictly speaking *anhydrite;* it only becoming gypsum on the further absorption of water. See note to following page.

have been much more rapid, had the water penetrated to the gypsum adjacent to the side walls; which would thus have been subjected to the enormous horizontal pressure caused by the expansion in that direction.

It was now evident, that remedies had been applied in the wrong direction. Time, however, was not allowed the water to reach the level of the tunnel (*); and the true remedy was sought, where it was to be actually found. In order to stop the progress of expansion, it was necessary to stop the ingress of the water. The only possible means of doing so was to lower its level, so as to dry the entire surrounding mass by a deep drainage.

A drainage culvert was placed at a minimum depth of 23 feet below the level of the rails, with a fall, at first of 1 in 250, and then of 1 in 500; its total length was 1440 yards, 516 yards being in tunnel, while 110 yards were in open cutting at its lower end (fig. 14). Figs. 5 to 9 represent the cross section of this tunnel-culvert; of wood in the first portion, and of masonry through the marl and the gypsum. The wooden lining of the shafts is shown in figs. 12 and 13, while the shoring of the open cutting is given in figs. 10 and 11. The walling through the gypsum was postponed till all movement should have ceased.

The execution of this work, not so remarkable in itself, as in the special circumstances to which it was applied, has answered every expectation; and has rendered safe a work of art, which at first appeared to be seriously jeopardized.

There is no need to further enlarge on the subject of this chapter; which, if dealt with in detail, would necessitate long descriptions that would be out of place here. A few examples of successful means adopted in specific cases, insufficient though they may appear, are more instructive than general investigations; which, by their very generality, are often difficult of application to the varied circumstances that present themselves in practice.

(*) Anhydrite slowly absorbs its two equivalents of water, required to become sulphate of lime. " Several varieties of sulphate of lime have been noticed ", M. Dufrénoy (a) remarks, " in which the proportion of water is less... There are numerous instances of this kind, but an examination of samples from them fully proves, that they consist of a mixture of anhydrite and of sulphate of lime. They appertain to gypsum, formed by anhydrite altered by the absorption of atmospheric moisture; in proportion as the alteration has been more or less complete in the last of these sulphates, so does the analysis give a greater or lesser quantity of water.

(a) " Traité de Minéralogie", vol. II, p. 378.

BOOK I.

SUPPLEMENT.

The title itself of this work, shows that it is not intended to include all questions connected with the approvisioning and the working of railways; two important divisions are, in fact, omitted; signals and stations.

The subjects treated of are those which form essentially the ordinary duties of the Engineer; while the ones omitted have been so, either on account of their very importance, requiring considerable space for their complete consideration, or on account of their special character, which entailed particular studies outside of those appertaining to engineering proper.

Signals at first were exceedingly simple, but the requirements for safe travelling and the ever increasing speed of the trains soon made it imperative to adopt more complicated arrangements. The block system, the interlocking of the distant signal levers with the points, and also their being worked from a distance, are all now being introduced in France. But it is especially in England, that this problem presents itself in its most complicated form; where the extraordinary activity of the traffic has led to the adoption of completely new arrangements, which under ordinary circumstances would not always be necessary nor capable of application, but which, in any general description of signals, should be explained and discussed. In their actual state, all the systems which are to all appearance the most perfect, even the block system itself, require the greatest caution. Chances of accidents, which might formerly have been almost overlooked, have become in the actual state of the working of railways in England, on some of the principal lines, a matter of serious importance; while the improvements conducive to safety have not progressed at the same rapid rate, as have the dangers arising from the increasing traffic, and the augmentation, perhaps out of proportion, in the number of the trains.

The duty of the electric telegraph, each day of greater importance as a

means of regulating the distance between the trains, now necessitates, on the part of signal engineers, a thorough knowledge of one of the principal branches of physics.

In France, where the traffic is much less active, safety has been much more satisfactorily ensured; for in no country are collisions rarer, and yet with comparatively simple arrangements of signalling. Nevertheless on portions of the principal lines, such as the Northern of France and the Mediterranean, fresh necessities have arisen. The block system, the concentrated working of the points and signals, as well as of those at a distance in one hut, has been in part applied, and will no doubt be soon further extended.

The automatic action of the trains, either to protect their rear, or to raise danger signals in front of them, has been, and is still being tried under various forms. In a word, it may be said, that the *science* of signals is only in its infancy, and that, which for so long has been deemed an accessory, is daily acquiring a greater importance and a more decided speciality (*).

The preceding observations, as to signals, apply equally to stations; and more especially to goods stations.

Even, engineers of considerable merit have been known to fail completely in their station arrangements; causing great difficulties and expenses in working the traffic, which can only be overcome by costly re-arrangements. Here, again is special knowledge required; indeed an engineer under such circumstances should consult and be guided by an experienced traffic manager, for it is not a question of fixed rules; since, in order to meet local requirements, much experience in the working of traffic is necessary. To consider properly the question of stations, numerous existing examples should be carefully studied, pointing out, in order to avoid them, the blunders there committed.

A treatise of such a nature would have been quite beyond the limits of the especially technical and scientific character of this work. Besides, and this alone would have quite sufficed, the author had not sufficiently studied the question to enable him to undertake so delicate a task; on these two grounds has the subject been avoided.

To make only one remark as to those stations, where the arrangements

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(*) Those, who are desirous of information as to railway signal arrangements in England, should peruse a little work by Mr J. W. Barry, M. Inst. C.E. entitled "Railway appliances." Though elementary, it is both useful and instructive, and contains much information upon the actual state of the question.

With respect to ordinary signals in use on double line railways, the work published in 1867, "Études sur les signaux" by M. Brame, "ingénieur en chef des ponts et chaussées", affords a very full description of them.

should be made subservient to commercial requirements; viz, as to goods yards. At those times, when the goods traffic is very heavy, and which recur periodically in France, great inconvenience is felt from the insufficiency of goods waggons. But this is not the true cause; for, excepting in rare cases, the amount of rolling stock is ample. It is not, however, judiciously made use of, owing to want of accommodation for loading and unloading. This is due in fact to bad station arrangements, and to defective details in working. Often has it come under the author's own eye, that, at a time when the want of trucks was being loudly proclaimed, station masters and inspectors of considerable intelligence have declined to receive any empty waggons, which would only have added to their already overcrowded stations.

Nor, can it be said, that the rolling stock is deficient, when, at one and the same station, laden waggons are kept weeks before being unloaded, while close by, increasing piles of goods are waiting to be despatched. The cause of all this, lies in the insufficient number of sidings, in the want of loading quays, and the means of intercommunication with the main line; thus, rendering the loading quays unapproachable, blocking up and rendering dormant the rolling stock, at the very time, when great activity is required of it.

A want of mechanical means, and tardiness of operations spread over a large amount of ground; in fact, the smallness of the discharging power per unit of surface in goods stations is the real fault to be overcome, not only during busy seasons, when the inconveniences are most felt and are most disorganizing to the staff, but, also, even under ordinary circumstances.

The rolling stock which is allowed, during a so great portion of its time, to remain stationary, only blocking up the sidings, should be utilized; but, before this can be done, the arrangement of the stations themselves must be radically altered. It may also be added, that the mechanical appliances for working the traffic should not be adopted, and the actual mode decided upon, except after careful examination. In England, these appliances greatly facilitate work; although at times, they are carried too far. Notwithstanding the advantages offered by concentration of the motive power, a division of it is preferable under certain circumstances; all depends on the very variable conditions of the traffic. We can in this but coincide with the exceptions held by M. Sartiaux, "ingénieur des ponts et chaussés", and connected with the traffic department of the Northern of France Railway (*).

(*) "Annales des ponts et chaussées," April 1876, p. 205.

M. de Coëne, engineer on the Western of France Railway, has made some very correct observations on this important subject, in his pamphlet : "Les chemins de fer en Angleterre. Construction et exploi-

The extreme complications in the numerous lines of traffic on a great railway system, crossing one another in every direction and necessitating a constant interchange of carriages, has given rise to difficulties, never even thought of at the commencement; and which moreover tend to materially increase the time lost by the rolling stock.

The decomposition of the trains and the assortment of waggons for their different destinations, as also the reforming of the trains, make up, with the loading and unloading of the waggons, the actual labour of a goods station. The first named series of operations often requires numerous lines of way and consequently a large space of land, often very difficult and sometimes impossible to find in proximity to the terminus itself.

Therefore, these various operations just enumerated are now often concentrated at a single spot, near to a junction for example; and called a marshalling yard.

A terminus unprovided with this addition, is often also a collecting station. But the converse is not true. A marshalling yard is a sort of large preparatory work-shop, provided with mechanical appliances; the chief work there being to assort the waggons according to their destination. It consists, essentially, of groups of lines connected with one another and with the main lines; and where the shunting operations are carried on, by means of horses, of turntables, of fixed capstans, of steam traversers, etc.

Much assistance is rendered in manœuvring, if the lines have a suitable inclination, so as to work by gravitation. These marshalling sidings become therefore a further argument for the application of a lever brake, of simple construction, to each goods waggon.

These few remarks suffice to show to those, who have not fully considered the matter, how important, how difficult, and most particularly, how very special is the subject of stations.

The preceding considerations have not alone, however, been the cause of the two voids left in this work. From the very beginning, it was deemed advisable to leave a sufficient space, for a cursory description of the progress that railway extension has given to the several branches of construction. Taken in an engineering view, this subject matter, if briefly described, enters more within the scope of this book, than do those that have been omitted. Such, also, has been the counsel of kindly disposed advisers.

" tation des gares de marchandises des grandes villes (20 juin 1876)," which Railway companies would do well to take note of. The "Société des ingénieurs civils" in France has, in a material way, shown its appreciation of the value of this work.

It may be fitting, to add in conclusion a few words upon some of the various subjects contained in the preceding chapters. As several years have elapsed, since the first volume appeared, in the original French, fresh facts have occurred; some of the remarks therein are open to modification, and any errors that exist should be rectified. Few there are who, after a lapse of ten years, can re-peruse their former labours and find them in accordance with actual facts, and consistent in themselves; and more especially is this the case, as regards railway matters.

The object of this supplementary chapter will, therefore, be to revise or to continue to the present date, some of the remarks contained in the preceding chapters. Throughout it, the number at the head of each paragraph corresponds to the one in the preceding pages, to which it relates. Where several non-consecutive paragraphs are referred to, it is the number first named that indicates the one, most connected with the note; while the other numbers are placed in brackets. By so doing, excessive sub-divisions, as also repetitions, are avoided.

CHAPTER I.

N^{os} 6 (9 and following).

The United States.— A reduced gauge of 3 feet has been adopted by a main line in the United States; viz the Denver and Rio Grande, which crosses the newly formed state of Colorado, with a widely scattered population, and also that of New Mexico, more thickly peopled. This line is ultimately intended to reach Mexico, when its total length would be 1856 miles. It is stated, that the cost of its construction will not exceed half the cost of a line of the $4'{\cdot}8''\frac{1}{2}$ gauge; while the requirements of the traffic will be amply provided for by this narrow gauge. The width of the rolling stock may be as great with one of $3'{\cdot}6''$ (and even with a 3 feet one), as on a line with a gauge of $4'{\cdot}8\frac{1}{2}''$. It is in fact a mere question of stability, and consequently of speed. As a proof of this may be mentioned, the closed waggons of the Denver and Colorado Railway, carrying 11 tons of compressed cotton.

There are, at present, five different gauges in the United States. If the difference is but slight, an extra width of wheel tyre may correct it : but, with a considerable one, the dangerous and complicated solution of the wheels sliding on their axle-bearings has now been abandoned.

British India. — The gauge adopted on the new lines in India, notably, the main lines of the Punjaub, from Lahore to Peshawur, as also that in the valley of the Indus (Scinde), has given rise to lengthy discussions in England.

By the appointment of a Commission, in 1870, to investigate the question, the English Government appeared to have taken a decided course; the maximum gauge adopted was $3'{\cdot}6''$, instead of that which had previously been used, viz $5'{\cdot}6''$. The only question, therefore, left to be decided was the expediency of placing it, at even a lower figure than $3'{\cdot}6''$. But this way of settling the question, created great opposition, not that any one showed any disposition to adhere to the $5'{\cdot}6''$ gauge; in fact, there seemed an unanimous disposition to discard it, even if the whole matter had to be gone into afresh. But the technical question was set aside, for another, which in the Metropolis could not fail to make itself felt; namely, strategetical interests. The adoption of the $5'{\cdot}6''$ gauge had, hitherto, been considered as decided upon, at least for main lines, on the necessary grounds of uniformity; not to be overlooked in frontier districts. With this argument strongly supported by M^r^ Fowler, the opinion of several Engineers who, like M^r^ Rendel, considered

a reduced gauge of even less than 3 feet, for the length of these lines, to be perfectly adapted for the requirements of a purely agricultural population, met with but little support. Indeed, if in 1874, the 5'·6" gauge was triumphant, it was especially due to political considerations, and in no way did it imply a condemnation of the narrower gauge in itself.

Sweden. — The example of Sweden has been often quoted, but not always accurately. While in Norway, the gauge has been altered from 4'·8 ½" to 3'·6", the reverse has taken place in Sweden; where new sources of traffic having arisen, the narrow gauge has lost nearly all its supporters.

There are, at the present time, in Sweden 2012 miles of the Railway, of 4'·8 ½" gauge, either constructed or projected, against only 400 miles of line of smaller gauges (4'·0", 3'·6", 3'·0" and 2'·6"). Constructed for a limited speed of 9 to 10 miles per hour, with very light rails, considerable economy may, without fear, be effected in the permanent way; as this can easily be improved should the traffic exceed what was originally contemplated.

This economy should not, however, be pushed too far, as is sometimes the case on narrow gauge lines; where, for instance, sleepers of small cube can be used. These short and slight sleepers however are far from economical; they last but a short time, about six instead of ten years, and their cube presents an unfavourable ratio to the surface they cover.

Hungary. — The scarcity of roads and their bad maintenance, from want of funds and of road materials, make the extension of light railways a matter of vital importance, for the development of the agricultural resources of that country. The State Railway promotes the execution of this useful public work; the advantages of which it will itself reap. Two sections, one of a length of 27 miles (from Valkani to Perjamos), the other of 23 miles (from Vojtek to Bogan), have been opened; the first in 1870, the second in 1874.

After careful consideration, the Austrian Company adopted for those lines the ordinary 4'·8½" gauge; introducing at the same time every possible economy that the particular nature of the traffic would admit of, especially reduced speed. The rails weigh 56 lbs to the yard; instead of 82 lbs, as on the main line.

Considering the easy nature of the ground, a narrow gauge line would have saved but little; whereas, with the ordinary one, setting aside altogether the inconveniences arising from a break of gauge, the old rolling stock of the main line could be utilized, thus, saving the expense of construction of special plant for the purpose.

These examples will suffice to justify the conclusion arrived at in the first

chapter (16), as to the adoption of the narrow gauge. It would be waste of time to enlarge generally upon the different gauges, it is a question, which should be solved in each particular case by the consideration of local conditions.

Herr Krauss, the well known mechanical engineer of Munich, has collected together in the following table the several elements of a series of types of narrow gauge locomotives constructed by him. Owing to the paucity of information extant on this subject, it appears useful here to insert it.

Locomotives for narrow gauge railways.

	1	2	3	4	5	6
HORSE POWER.	7	20	45	60	100	150
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Diameter of cylinders.	4	$6\frac{1}{4}$	$7\frac{7}{8}$	$8\frac{7}{8}$	$9\frac{7}{8}$	$11\frac{3}{8}$
Length of stroke.	$6\frac{1}{4}$	$11\frac{3}{4}$	$11\frac{3}{4}$	$15\frac{3}{4}$	$19\frac{5}{8}$	$21\frac{1}{4}$
Diameter of wheels.	$15\frac{3}{8}$	$22\frac{1}{2}$	$22\frac{1}{2}$	$31\frac{1}{2}$	$39\frac{3}{8}$	$39\frac{3}{8}$
Actual pressure 175 lbs. per sq. inch.						
	Sq. feet.	Sq. feet.	Sq. feet.	Sq. feet.	Sq. feet.	Sq. feet.
Heating surface.	56·0	133·4	265·8	318·5	432·6	669·3
Grate surface.	1·3	1·9	37	5·4	6·5	7·7
	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.
Distance between the axles.	3·0	3·9	5·0	5·6	6·6	8·6
	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.
Coal capacity.	2	4	10	$14\frac{1}{2}$	30	30
Water d° (for the minimum gauge but	Gals.	Gals.	Gals.	Gals.	Gals.	Gals.
increasing with the wider ones). .	42	115	347	493	594	706
	Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.
Weight in working order.	$1·19\frac{1}{2}$	$4·18\frac{1}{2}$	8·17	11·16	17·14	23·12
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Load drawn upon inclines of 1 in 20.	2	10	15	20	22·5	25
1 in 40.	3·5	17·5	26	35	40	45
1 in 60.	5·5	27·5	42	55	60	67·5
1 in 80.	8	40	60	80	85	95
1 in 100.	10	50	80	100	105	115
1 in 200.	15	80	120	160	170	200
1 in 500.	20	100	160	210	220	260
Level.	30	150	240	300	320	380
	Miles.	Miles.	Miles.	Miles.	Miles.	Miles.
At a speed per hour of.	7	7	7	7	12	12
	Ft. ins.	Ft. ins.	Ft. ins.	Ft. ins.	Ft. ins.	Ft. ins.
Width of gauge.	1·8	2·2	3·3	3·3	4.0	4·0
	Yards.	Yards.	Yards.	Yards.	Yards.	Yards.
Minimum radius of curves.	$5\frac{1}{2}$	22	44	55	77	87

Under ordinary circumstances, the consumption of coal per effective horse power per hour is 4·95 lbs, and 3·6 gallons of water.

When lignite, wood, or turf are used, both the stowage capacity and the size of firebox must be increased.

Engines of 150 horse power are suitable for goods traffic on narrow gauge lines, and for shunting purposes in main line stations. Where the rails are light, three pairs of wheels are used.

CHAPTER II.

Nos 49 (and 51).

The opinion expressed in these paragraphs upon the preference to be given, to a straight line instead of to a curve, in the bearing surface of the head of the rail, very generally prevails at present; as an example, may be cited the new 66 lbs steel rail (Pl. XXXVIII, fig. 6) of the Northern of France. The bearing surface, which consisted at first of a circular arc of $6\frac{3}{8}''$ radius, its chord being $\frac{7}{8}''$ long, has been replaced by a straight of this length.

No 62.

Sometimes a decided tendency has also been observed in the fastenings of the intermediate sleepers to loosen, and to lift. This is most marked with certain proportions between the axle loads, their distance apart, and that of the sleepers. Under the influence of the strain brought upon two loaded spans, separated by two unloaded ones AB,DE (Pl. XXXVIII, *fig.* 18), it can happen, with too yielding a rail, that the strain on the centre sleeper, *c*, may be null or even negative. When the rail, in its tendency to rise at that point, would draw the fastenings with it.

CHAPTER III.

Nos 69 to 72.

In this examination of the dimensions of rails, considered as subject to transverse deflection, the longitudinal strains of tension and of compression in the fibres have alone been considered. In consequence of the size of the total section of iron rails and of the thickness of the web, it was useless to dwell on the shearing strain, and on that of longitudinal sliding, which is greatest in the middle of the web.

In cast steel rails, where a portion of the metal stored in the head has been placed there at the expense of the web, care should be taken, by means

of the formula in the note (*), lest the reduction of the latter be not pushed too far as regards this sliding action.

For instance, in the 66 lbs rail of the Northern of France, where the web is only $\frac{1}{2}''$ thick, this strain at the neutral axis in but 3.17 tons per square inch. The longitudinal strain of the extreme fibres attains :

	IN THE HEAD.	IN THE FOOT.
	Tons. Cwt.	Tons. Cwt.
With a new rail.	3 · 18¼	4 · 1
— ¼″ worn off the head. .	4 · 6	4 · 6
— ⅜″ d° d° . .	4 · 10½	4 · 12½

N° 74.

It is becoming more and more general to have the rail-joint unsupported; at present it has indeed become of general application, even for steel rails, where notching the foot in objectionable, an operation, which the sleeper joint renders unnecessary. The unsupported joint with its advantages is however preferred; while the tendency to move is counteracted by divers expedients, which are be noticed later on, p. 496, etc.

N° 84.

Grooving the rails in order to receive fish-plates of a nearly rectangular form, only tried however on a portion of the Orléans Railway, has been long since given up. The tension of the bolts is limited by making the faces of the rail tolerably inclined towards the horizontal.

N° 100.

Strains in fish-plates. — The method here indicated for calculating them supposes, with an unsupported joint, that the length of the fish-plates is less, than the distance between the centres of the two sleepers on each side of the joint.

At the present time, attempts are often made to diminish the strains in fish-

(*) Suppose a bar with one end rigidly fixed, and loaded at the other with a load P. The shearing strain will also be represented by P. And if the cross section be constant and symmetrical relatively to the mean plane wherein P acts, then the longitudinal sliding strain per unit of surface, R″, at the point where the breadth of the bar is u, and its distance from the neutral axis is v, is represented by

$$R'' = \frac{P}{Iu}\int_v^V uvdv.$$

V being the value of v for the extreme fibres.

plates, either by reducing this distance, or by increasing their total height; which, as will be seen farther on, is also one of the means of counteracting the longitudinal displacement of the rails. As the same length of fish-plate is retained, if not indeed increased, it often happens, that they are extended even to the centre of the sleepers. Such is the case on the new line from Bebra to Friedland (Pl. XXXVIII, figs. 7 and 8). The fish-plates are 1'·11" long, the same as between the centres of the sleepers.

In order to enable the fish-plates to re-establish continuity without being themselves more strained than is the rail, the following condition should always exist; viz : $\frac{Va}{I}=\frac{V'a'}{I'}$: a being the intermediate span, a' the joint span, V and I having reference to the rail, V' and I' to the pair of fish-plates. A greater molecular strain is, however, always allowed in the latter, than in the rail.

In the form of permanent way here referred to, the fish-plates become as it were, like two beams coupled together, resting upon the sleepers by means of the foot of the rails, and carrying the unsupported part of the latter. But these two beams must not be considered as having their ends loose. For, gripped in the hollow of the rails, they take, under the influence of a wheel in the middle of the span, the same form as the rails do; and, since these are assumed to have their ends rigidly fixed, it follows that the fish-plates like them have a horizontal tangent at each end, one at the middle, and two points of contrary flexure at $\frac{1}{4}$ of the span from either extremity.

Supposing the wheel load, P, to be transferred in its entirety to the fish-plates, the most unfavourable hypothesis for them, and one justified by the great relative flexibility of the two rail-ends, then the equation at the middle of the fish-plate will be, $\frac{EI'}{\rho}=\frac{P}{2}\times\frac{a'}{4}$; whence $R=\frac{EV'}{\rho}=\frac{1}{8}\frac{V'Pa'}{I'}$. I' being the moment of inertia of the double section.

The ratio $\frac{I'V}{IV'}$, which with fish-plates is always less, as has been seen, than 0.25, is of course much greater with fish-plate chairs. Thus in the double-headed rail of the Mediterranean line (Pl. VI, figs. 32 to 36) we have in units of an inch :

	RAIL.	FISH-PLATE CHAIR
Weight per yard run	$73\frac{1}{2}$ lbs.	$93\frac{1}{2}$ lbs. the pair.
Area	7·58 sq. ins.	8·90 sq. ins.
Moment of inertia I. of entire section	22·564	16·748
Moment of inertia I. of section at centre of hole	22·542	16·693
V	2·625″ (height 5·25″)	3″ (height 4·25″)
Ratio $\frac{I}{V}$ Entire section	8·595	5·582
Ratio $\frac{I}{V}$ At centre of hole	8·587	5·564

It is the reduced area that should be taken with fish-plate chairs; for, as there are three bolts the centre hole occupies the section of rupture.

Thus, $\frac{I'V}{IV'} = 0.627$; a ratio, relatively great, which follows from the large area required by the complicated form and the large dimensions of the fish-plate chair.

It is not unnecessary to add, as a secondary imperfection of the fish-plate chair, that its theoretical centre of deflection does not coincide, as in the case of the ordinary fish-plate, with the centre of deflection of the rail; the divergence is one and a half inch.

N° 101.

The position of the fish-plate bolts may be justified as follows. The upper head of the rail produces on the top of the fish-plate a thrust $Q = \pi\left(\frac{1}{\text{tang}\,\alpha} - f\right)$, and the lower head on the bottom of the fish-plate a thrust $Q' = \pi\left(\frac{1}{\text{tang}\,\alpha'} - f\right)$. The total thrust is therefore $Q + Q' = \pi\left(\frac{1}{\text{tang}\,\alpha} + \frac{1}{\text{tang}\,\alpha'} - 2f\right)$; the two thrusts are applied (Pl. XXXVIII, fig. 15) in the vertical planes A, B, distant l apart. The point of application of the resultant is on the straight AB, and at the middle M, if $\alpha' = \alpha$. A single bolt, placed at that point, would counteract the thrust, $= \frac{3}{8}\frac{P\alpha'}{l}\left(\frac{1}{\text{tang}\,\alpha} - f\right)$.

But the fish-plate would yield horizontally by buckling. Therefore, the single bolt should be replaced by two as nearly opposed as possible to each of the thrusts Q, Q′. These thrusts are, however, applied at the top and bottom edges of the fish-plate; and the deflecting strain to which it is submitted does not allow of its being weakened, as in the rail, near to the extreme fibres. The bolt holes can, therefore, only be made near to the neutral axis; the bolts then must be placed at the half height, and, in the vertical planes A, B, at o and o'.

It is evident, that when $\alpha \doteq \alpha'$ (which is generally the case), each bolt receives a strain, and consequently has also a diameter, the double of that it would otherwise have, if it were *directly* opposed to the thrust which it counteracts.

N° 107.

Some restriction should now-a-days be placed upon what was previously said, with regard to the facility with which the Vignoles rail can, by means of one or more sleepers, be rendered sufficiently continuous to counteract its tendency to longitudinal displacement. Experiments made on homogeneous cast rails, prove that this metal, rather hard for the head to wear away without deformation, prevents notches being made in the foot of the rail. When a single sleeper suffices to ensure the rail connection, one can always apply at the lower end one or two stop-blocks; such, however, cannot be done, when the joint has no bearing under it. The power of using these blocks, is not however, as a general rule, a sufficient compensation for the advantages claimed by that form of permanent way. The two modes of counteracting longitudinal slipping in the rail, either by stop-blocks or by notches, cannot therefore be used together.

The difficulty is overcome by making one of the fish-plates butt at one of its ends against the wood screws, or the spikes, of the sleeper next to the joint. The ordinary form of fish-plate does not, however, come down so low as their heads; and it must also be kept at a mean height. An intermediate piece is required therefore to make up the difference, to be placed between the fish-plate and the fastenings, and compensating for the defects both of height and of length; as on the Eastern of France Railway. Or else the fish-plate may be lengthened, and extended downwards. As was done on the permanent way of the Bebra and Friedland line (Pl. XXXVIII, figs. 7 and 8).

The same principle has been recently applied upon the Mediterranean system, where an unsuccessful application of a particular kind of steel pin was made, but which wore away most rapidly. The stop fish-plate proposed by M. Couard, and shown in figs. 9 and 10, Pl. XXXVIII, butts in its lower part against the sleeper next the joint. There is reason to suppose, that a single stop fish-plate would suffice. While being tried it was placed sometimes on the inside of the line, and sometimes on the outside; its fellow being an ordinary fish-plate. The simultaneous use of two stop-fish-plates was also tried; and both systems were applied under identical conditions in order to afford a conclusive comparison. The new form of fish-plate was placed chiefly in curves of small radius, at the bottom of heavy

inclines, and near stations at points where the action of the breaks is especially felt.

The Eastern of France stop-plate has been for some considerable time in use on the Hessian Railway (Hessische Ludwigsbahn), with the joint unsupported.

A fish-plate with a projection downwards has been recently introduced on the Berg-and-Mark Railway. It consists of an angle iron; the lower horizontal edge of which turns down upon the foot of the rail, and is prolonged outside, doubling down to nearly the underside of it. The outside fish-plate laps round the head of the rail, rising almost to the top of it.

The fish-plates are 24 ins. long, the same as the distance between the centres of the sleepers next the joint; the lower projection of the inside one being notched, to receive the spikes directly.

The following are their weights.

1 outside fish-plate.	$31\frac{1}{2}$ lbs
1 inside d°	$22\frac{3}{4}$
6 bolts.	10
4 spikes.	$2\frac{1}{2}$
Total weight per joint.	$66\frac{3}{4}$ lbs.

By this means the resistance of the fish-plate to deflection is at the same time increased. This form of fish-plate is nearly the same as the "Dockray" one, described by M. Desbrière(101, note); which is arranged for a symmetrical rail, and laps round the lower head.

Steel rails. Notching the foot. — A very remarkable instance of the effect of notching the foot of steel rails is observable with Bessemer rails. As this effect had not been noticed when the first volume of this work originally appeared, a few remarks thereon may be deemed advisable.

Rails, undergo when cold, two distinct operations; making the holes for the fish-plate bolts, and, in the case of the Vignoles rail, notching the foot, to prevent longitudinal displacement.

In paragraph 107 it was stated, that "Fault is sometimes found with this latter
" arrangement, which is the most usual, on the ground of its weakening the
" rail; but, as the fractures do not happen more frequently at the point
" where the holes occur, than elsewhere, both positions may be regarded as
" alike."

It was then only a question affecting iron rails; yet it is nevertheless applicable at the present time. For the simple reason, that intermediate notches, although considerably reducing the power of resistance of the rail, especially to impact, yet leave a sufficient margin of that power to prevent frac-

tures, which seldom occur on a well maintained line. — But it is altogether different as regards Bessemer rails; the diminution thereby in their resisting power being very great.

It is easily understood, that the same notch will weaken more a bar whose dimension is much reduced; but its influence is out of all proportion to the loss of metal. This injurious effect is besides much greater in the Bessemer rail of the Lyons and Mediterranean Railway, than in the iron one of the same line; and yet the first (349) differs only from the second, in having the foot a little wider and in an increased weight of nearly $6\frac{1}{2}$ lbs per yard run; a singular paradox, especially when the light Bessemer rails are taken into consideration (65 lbs per yard instead of 82 lbs), and which have been adopted so generally with such satisfactory results.

It will be advisable to take this opportunity of considering the actual state of a question, which seems to have escaped the attention of engineers. In carrying out the experiments on impact tests on iron rails, some with and some without being notched, the notches being square in form and placed at the point of impact, it was found, that the products of $P \times h$ required to produce fracture, were as 100 to 70 for iron rails of the best quality, and as 100 to 50 for those of ordinary quality.

In the experiments on Bessemer rails, the following ratios have been obtained:

Hard metal, with half round notches. . . .	as 100 to 50
d° d° square notches.	— 100 — 3
Softer metal, d° square notches.	— 100 — 20

M. Sevène, the Engineer in chief of the Orleans Railway has kindly forwarded the following results to the author.

" Paris, 16th June 1874."

" My attention has but recently been called to the weakening of the Vignoles rail " by notching the foot of the rail.

" Ever since we first used the Vignoles rail, we have always had them notched " over the two middle sleepers, 3 feet apart. Any weakening caused by this short " interruption in the connection we took no heed of; for in reality, as far as regards " iron rails, it appears but trifling. Experience has shown, that no appreciable in- " convenience arises from it.

" The same arrangement is in use, with steel rails on the Cantal lines. They have " had six years wear; the total length laid with steel rails is nearly 16 miles. The " number of proved fractures, extending over the six years, has been twelve; of " which six have taken place at the notches.

" This result is not alarming; still it shows a weak point.

" At the request of the Creuzot Iron Works, we have there made various experi- " ments on steel rails during manufacture; and with the following results.

" *Statical test* (3'·3" bearing).
" The rail, untouched, as manufactured, broke under a load of 55 tons.
" The rail, notched, broke under a load of 30 tons.
" *Impact tests* (bearing 3'·7" weight of ram 6 cwt).
" The unnotched rail only fractured under a fall of 10'·6" to 12'·0".
" When the blow from the ram fell on the part of the rail where the notch " was, it fractured with a fall of 2'·0" to 2'·3".
" This last result is striking, and proves that the weakening of the rail by notching " is very considerable.
" As the notch must of necessity occur on a sleeper, the effect referred to might " not be of so much importance, if it was certain that the sleeper would afford " a perfect bearing; such however is not the case, for if from any defect in the " packing, the rail where the notch occurs should be unsupported, it is mani- " fest that the notch materially increases the chances of fracture.
" It is much to be regretted, that this simple and efficacious form of stop should " be abandoned; which is, in my opinion, one of the principal advantages of the " Vignoles rail.
" The various arrangements, that have been applied up to the present time in its " stead are but little satisfactory; and care must be taken lest the change be from one " inconvenience to a worse one. The matter should be well studied and experi- " mented upon.
" Meanwhile, I adhere to notching, even for steel rails; which are however but " little used on those of our lines that are laid with the Vignoles rail, and with " but inconsiderable traffic."

M. Ledru, Engineer in chief of the construction on the Eastern of France, has very kindly transmitted the following observations to the author :

" Paris, 27th of June 1874.

" We have no experiments on the effect produced on notched rails, by impact. " We have only been able to prove, how much that resistance is affected by the least " crack in the foot.
" Thus, although notches, which always coincide with the sleepers, are evidently " less dangerous than cracks, we have nevertheless thought it advisable to dispense " with them. With the joint on the sleeper, we stop the longitudinal slipping by " means of a bed plate, on which the notched ends of both rails are placed. But " with the unsupported joint, as adopted on our new permanent way with a rail of " 61 lbs per yard, we make use of a small stop-plate *c, c* (Pl. XXXVIII, fig. 16), against " which the end of the fish-plate presses."

The Northern of France Railway has been induced to apply, at the lower end of the rail morely one (or two, in case of need) stop-wedges (106 and 107). The Southern of France line, not using the Vignoles rail, feel no interest in the matter.

Without having any of the serious consequences attached to notching, especially when of a square form, making the holes for the fish-plate bolts in

the web of the rail, seems to affect the molecular condition of the metal considerably more in steel than in iron. For this reason, many engineers insist on having the holes drilled, and not punched; while others will allow a small hole, half the diameter to be punched, afterwards to be drilled to its full size, the drill carrying off the metal which the previous tool had injured.

Punching appears after all to be admissible, provided the outside hole be not too near to the end of the rail; or else the web might be liable to crack along the lines of the centres of the holes. In the United States, however under no circumstances is punching allowed with Bessemer rails; and in England drilling is almost the universal practice.

These facts prove, that Bessemer metal, of that degree of hardness which is generally sought for in the case of rails, is much more affected when worked cold than is wrought iron. When in the form of plates, it cannot escape this effect, which has been ascertained from experiments in connection with rivetting. Great precautions will therefore have to be taken in those mechanical operations to which it is subjected; especially if the steel is not very soft.

CHAPTER V.

N° 162.

Permanent way of the Saint-Gothard Railway. — A 75 lbs steel rail, of a depth of 5 ins., has been adopted for the entire line. The sleepers will be, on the subalpine lines, of fir, placed 3′·3″ apart from centre to centre; while in the approaches to the great tunnel they will be of oak, 2′·11″ apart. Under a load of 8 tons, which may be taken as the extreme load on one wheel with the locomotives selected, the maximum strain on the rail will be $6\frac{1}{4}$ tons per square inch. It still remains to be settled, whether iron or stone shall be used, instead of wood, in long tunnels, where the sleepers decay rapidly.

Kyanising has been applied to the line on the plain of the Ticino, part o which has already been opened for traffic. Every cubic yard of oak was found to absorb nearly $1\frac{1}{2}$ lb of bichloride of mercury, while with larch quite that quantity was used. The wood is immersed in the cold liquid contained in fir cases, and kept there for ten days; the proportion of the solution is $\frac{1}{150}$.

This process has been somewhat fancied, owing no doubt to two advantages which it offers; it is effective and simple. But it is expensive; and, if it does not require, as do those at present generally in use, a somewhat complicated plant, it is highly injurious to the workmen employed.

N° 171.

It is well known, that galvanized iron, used as a covering, has only met with partial success. Owing to the much greater degree of expansion of the zinc than of the iron, the coating formed by the former detaches itself; and, then swelling up, ends by separating itself irregularly over the surface. The places left bare on the sheet-iron then oxidise more rapidly; being rendered still further liable to do so by galvanic action.

The same effects do not take place with spikes, which are exposed to slighter variations of temperature; and where, besides, the dimensions are relatively very slight.

CHAPTER VI.

N° 175.

At Gelsenkichen-am-Ruhr, the furnace slag is discharged under a shower of water; the rapid cooling which takes place reduces the mass into pieces of about $\frac{1}{4}''$ to $\frac{3}{8}''$ diameter, well adapted for road and railway ballast. At Siegen, the dross is discharged under a jet of steam, the effect produced being quite different; the mass, without breaking up, assumes a fibrous texture much like that of asbestos. It is used as a covering for steam pipes.

N° 176 (*alternating the rail-joints*).

The Northern of France Railway, which still adheres to the sleeper joint, has for some time past been laying the rails, so that the joints of each line of the way do not both occur on the same sleeper. It appears somewhat inconsistent, thus systematically to disturb the unison of the impulses to which vehicles are at the same instant subjected; the tendency of this alteration being to impart to them an undulatory movement. Though, the inconvenience may be but slightly felt on a line kept in such good order as is the Northern of France, yet this alternation of the joints is, in principle, hardly to be justified. On the contrary, the causes which tend to impart to the carriages a position obliquely to the centre line of the way, should be eliminated; those intermittent disturbances, arising from the joints, should be made to act at the same moment on both wheels of the same axle. This is borne out by experiments made in Germany.

It is especially in curves, that the principle in question of laying down rails seems to have some show of reason. For by this means the resistance of the inside rail is opposed to the pressure of the wheel flanges, tending to drive the sleepers outwards; experiments on the matter have been made both in England and in Germany; and this method has been entirely given up. "The carriages", says Herr Ed. Sonne, Professor at the Polytechnic School at Stuttgart (*), "sustain very marked horizontal "oscillations on those sections where the joints have been alternated; the Com- "panies have decided against this modification."

CHAPTER VII.

N° 177.

The example of Bavaria induced the Directors of the Wurtemburg line to try the use of stone-blocks, instead of sleepers. They were first layed down between Wasseralfingen and Goldschöfe, and considered satisfactory; it appears likely that their application will be extended. The blocks are smaller than in Bavaria, being $1'.10'' \times 1'.10'' \times 11''$ deep. This reduced height is partly due to the mode of fixing the rails; not with pins, but by screws and nuts, running entirely through the block. These screws are $\frac{5}{8}''$ diameter, while the holes are $\frac{3}{4}''$ diameter.

Herr Morlok, the engineer of the line, has had a simple little contrivance constructed for the purpose of boring the holes. The block, set and firmly fixed on a frame by holding down screws, is attacked from below by a vertical drill; the hole thus clears itself. This apparatus, which is much more exact than the chisel, does away with irregularities in chipping; which are unavoidable with manual labour.

CHAPTER VIII.

N° 191. — *Metallic Permanent way of Herr Hilf* (Pl. VIII, fig. 28).

The objections, that this rail appeared at first to present, were briefly pointed out in the text. Since then, the inventor has improved some of the details; especially by substituting bolts in the place of rivets, to fix the rail to

(*) Handbuch für spezielle Eisenbahn-Tecknick. — Von Waldegg. Vol. 1, p. 272.

the longitudinal bearer, and in replacing the T iron distance-pieces by tie-rods placed higher up, fixed to the rails themselves, and thereby ensuring more fully the retention of the inclination (Pl. XXXVIII, figs. 12 to 14). The ballast comes up to the level of the lower part of the head of the rail. The objections to which this system gave rise would, however, appear to a great degree still to exist.

Such however is not the conclusion to be drawn from an extended trial on the Nassau Railway; laid down there first some ten years since, it is now applied on that line for a length of over 60 miles. It can hardly be said therefore to afford but promises. It has gathered round about it the most competent opinions. The committee of investigation at Berlin in 1873 decided, that it alone, of the many forms of experimental metallic permanent way, presented any reasonable chances of success, and deserved to be submitted to a lengthened experience. The reunion of German Railways has also presented to the inventor one of the prizes, which it awards for technical progress in matters connected with railways.

In spite therefore of appearances, the future promises well for the metallic permanent way of Herr Hilf. It is doubtful however, even in Germany, if he can count upon this future. When one compares the Barlow rail, heavy, though simple and consistent, with Herr Hilf's mixed and complicated rail, it is difficult to recognize, in the former, but the outline and germ, and to find that the second represents progress. Now, as in 1867 (192), we would rather reverse the conclusions of the above expressed opinion; only as to its form, however, be it well understood. The question also, of the manufacture of the Barlow rail, we would still again reserve.

However the relative success of the Hilf permanent way in Germany has awakened attention in Belgium; where the study of entirely metallic permanent ways, offering as it would a new outlet for their iron industry, although somewhat dormant, is not entirely extinct. Up to the present however, the results of the experiments carried on in Germany, are being awaited; and perhaps this is the best thing to be done. England, where the same stimulus exists, has professed for a long time, and will no doubt continue to do so, a otal indifference as regards a metallic permanent way. Most engineers there onsider its economy, very doubtful at best, to be only a secondary question. They adhere to the cross-sleeper system, safer it is deemed, and to chairs; even to their retention in some of the extremely rare cases, where the double-headed rail has given way to the flange rail.

The following table shows the weight of Herr Hilf's permanent way :

2 rails 19'. 6" long, at $50\frac{1}{4}$ lbs per yard run.	660 lbs.
2 longitudinal bearers $\frac{3}{8}$" thick 19'. 3" long, at $66\frac{1}{2}$ lbs per yard run. . .	854 —
33 bolts and plates, to fix rails to longitudinal bearers.	46 —
3 tie-rods with 12 wedge plates each, and 18 screw bolts (*).	53 —
2 pairs of fish-plates and bolts.	44 —
	1657 lbs.
Being, per lineal yard of single way.	255 lbs.

" Two notches, in the foot and at the middle of the rail ", says the German description, " to prevent longitudinal slipping ". No attention appears to have been given in this respect to any of the conditions special to the Bessemer or cast metal rail.

Inventors have at times a thirst for progress. They cannot be reproached for this, on the contrary ; but they press forward so rapidly, that it is almost impossible to follow them. Herr Hilf has recently introduced into his system various modifications, one of the most important being the use of joint sleepers (**). The cross sleeper, exactly similar to the longitudinal bearer, is 8'·6" long ; the longitudinals rest on the flat, aided by their side pieces and by the centre rib. They are curved so as to give an inclination of 1 in 20 to the rail. The rail is made as much as 29'·6" long, while the longitudinal is 29'·5"; the connection between the two lines is affected by means of a single round rod at the middle of the length. Notwithstanding their length, the longitudinals are not bent when laid down on a curve; their great lateral rigidity preventing it. They then form a polygon; and upon each of them, the curved rail is, at the middle and at the ends, at an equal distance from the centre line.

N° 193.

Experience, has not confirmed the hopes entertained respecting the Hartwich rail; expecially as regards lines run over at high speeds. Two lengths of $2\frac{1}{2}$ miles each, laid the one with the Hartwich rail, the other with the Hilf, were placed alongside each other on the level on a double line section; the latter type showed a decided superiority as far as regards facility of maintenance. If this system should eventually prove the best, it will only be another proof, as far as permanent way is concerned, that much dependence should not be placed upon " a priori " judgments.

(*) On well settled embankments, and on straights, two tie-rods will suffice.

(**) " Eiserne Oberbau ", C. Kreidel, Wiesbaden, 1876.

The Rhenish Railway, which had at one time nearly 90 miles of the Hartwich rail, has already replaced a great portion of it with the ordinary permanent way.

N° 198.

In the examination of the several systems of entirely metallic permanent way, those only have been described in detail which appeared to have some chances of success, or whose author's names rendered them worthy of consideration.

It is only fair to acknowledge, that in France M. Langlois of Dreux was one of the first, who tried to introduce metallic sleepers; but none of the three schemes he proposed appear satisfactory. In the two first the rail itself is inclined, and is consequently non-symmetrical; in the second and third, the end of the sleeper did not project beyond the outside edge of the foot of the rail, it was much too short. In the third the rail was symmetrical, and the inclination was given it by a hollow in the sleeper. The mode of fastening does not, besides, appear to be very effective.

It may also be added, that the very narrow section of the Zorès iron used by M. Langlois, affords the rail lengthways too narrow a support; and that the sleeper itself has an insufficient bearing on the ballast. It would be impossible to reckon on the stability of such a permanent way, wherever a fair rate of speed was required.

N° 200.

The tendency now-a-days is generally to allow a greater amount of cant than previously. The rules upon which it is based seem however to vary much, and appear to be laid down more by whim and fancy than to be the result of regular discussion or careful observation. Considerable differences are, besides, admissible even in principle; for the cant must vary in proportion with the radius of the curve and the speed, with the spacing of the axles, and with their more or less exact parallelism when on the curve.

On the local line of Avricourt to Blamont and to Cirey (Meurthe-et-Moselle), the engineers, Messrs Varroy and Bauer, have made use of the following formula, $S = \frac{20 + 0{\cdot}012V^2}{R}$; V being the speed in kilometres per hour, R the radius of the curve in metres, S the cant in metres. With $V = 28$ miles (the greatest speed allowed) and $R = 18$ chains, $S = 5\frac{7}{8}$ inches ($0{\cdot}148^m$). In curves of 30 chains and under, an additional screw was added at some of the intermediate sleepers, on the outside of the outer rail.

CHAPTER IX.

N° 212.

It is hardly necessary to say, that the Bessemer rail cannot be curved by impact; even if no notches are made in the foot.

N° 234.

In the United States, gates are not generally used at level crossings; but, in a flat country and when at the level of the ground, the railways are mostly provided with fencing. The companies considering it preferable, and to their advantage, thus to avoid the legal consequences of cattle straying on to the line. When the line is without fencing they are pecuniarily responsible; but they cease to be so, if it is enclosed.

N° 237.

These proposed regulations, approved and rendered applicable by a ministerial decree, are now in force.

N° 240.

The arrival of trains, at several places on the Mediterranean line, is announced by electricity to the gate-keepers; for instance at the level crossing of Bois-le-Roi. The ringing of the bell, warning the gate-keeper of the departure of the train from Fontainebleau towards Paris, is worked by the signal-man at the Tyer hut, at Bois-le-Roi.

As soon as this signal-man is advised of the departure of a train from Fontainebleau northwards, he closes the circuit, and the bell warns the gate-keeper to close his gates. On the Paris side, as trains going towards Lyons are visible at a great distance, it is only necessary in order to ensure security, that the gate-keeper should comply with the ordinary regulations prescribed for the superintendence of the line.

Warning the crossing-keepers by electricity is also in use on the Northern of France; the circuit being closed by the automatic action of the train itself upon a pedal about $1\frac{1}{4}$ mile in advance of the crossing. The apparatus presents some ingenious details. It is sufficient to mention here, that its prin-

cipal feature is to withdraw the pedal, acted upon by the first wheel, from those which follow.

On the Mediterranean line, some of the apparatus consist simply of a bell, of a wirepull, and of a pedal; the last named is acted upon by all the wheels, which is decidedly prejudicial to the preservation of the several parts, however simple they may be.

The engineers of the Mediterranean line also endeavour, but by another contrivance, to ensure the timely closing of the level crossing gates by an electrical connection between the gate-keeper and the adjacent station. Instead of the gate-keeper receiving the order from the station to interrupt the cross traffic, it is he, who when in doubt, that is in case of any delay in the train, asks if he may keep the gates open; which, when unanswered, is considered as a negative reply. Thus is obviated the usual objection urged against the message being sent to the gate-keeper by the station, of possible derangement in the apparatus, or of a signal not being noticed.

N°s 242 and 243.

The Eastern of France Railway has recently had under trial some new descriptions of level crossing gates, both turning and swivel. They are made entirely of angle iron; even the bearing posts are of metal, and consist of short lengths of old Vignoles rails, which considerably simplifies the iron work. The revolving gate is either for a 13'.0", or a 16'.6" opening; and works outwards from the railway.

For much frequented roads sliding gates are preferable. They can be placed exactly at the edge of the ordinary width of the line; thus reducing the length of the crossing to a minimum. Vehicles can come close up without in any way interfering with their being opened; and, when needed, they can be closed very quickly against any vehicle that may arrive at the wrong time.

The company propose placing this type of gates at all the most frequented roads, where a width of 20 feet is requisite. The two descriptions here referred to are made use of for crossings between 13'.0" and 16'.6" wide, where previously wooden hinge-gates had been employed. It is the increased cost of sliding gates, about 75 per cent, which prevents their use being more general. The new types, being both rigid and yet light in construction, have been approved of by the Government authorities.

Children often climb on to the gates. Several accidents have taken place from this cause upon sliding gates on the Mediterranean line. Two children

were thus injured, one on its head, the other on its arm, by being jammed between the sliding gate and the upright post. In one of these cases, the gate was being worked by a person unacquainted with its working; the keeper himself meanwhile being engaged moving the one at the opposite side. Although railway companies cannot by any means be held responsible for accidents of this kind, yet the Mediterranean railway endeavour to avert them, by putting sheet-iron on the gates and by locking them; the gate-keeper alone having the key. These are very praiseworthy, and almost excessive precautions.

N° 258.

Through-crossing used in Germany, called "Englische-Weiche". — On a through-crossing, as commonly constructed, with its parts fixed, a train can but follow the line it is upon.

The importance however of simplifying shunting operations in stations, or rather of concentrating them into a smaller space and especially of increasing in stations the communications between the different lines, may lead to the duties of the through-crossing being extended. Such is the object of the arrangement shown in fig. 11, Plate XXXVIII. German Engineers, who are beginning to apply it, only in stations however of course, call it "Englische-Weiche"; it being of English origin, and known under the name of double slip points. It is an ordinary through-crossing with the addition of, 1st four lines of rails R, R′, S, S′, connecting directly both sides of the obtuse angles of the rails of the two lines crossing each other, etc.; and 2nd of four sets of points C, C′, D, D′, allowing a train to be run at will, either by the through-crossing on to the continuation of the line on which it is upon, or by means of the connections on to the line crossing it.

In the second case, the wheels find a continuous rolling surface, without gaps, excepting at the crossings K, K′.

This system is only applicable to crossings with a very oblique angle; otherwise the very short distance between the crossings K, K′, would necessitate too sharp curves for the connections. Local conditions may lead to the addition of only one connection, and consequently requiring only a single pair of points.

The meeting at Munich on technical engineering matters has stated its opinion as to this apparatus in the following words:

"Its utility, as far as regards economy of space and rapidity of shunting, does "not appear doubtful; but it seems liable, however, to cause a running off the "line."

It is however to aid in shunting operations, which are only partial in character and executed at a reduced speed, that this apparatus is specially intended.

N° 263.

It is possible to avoid this inconvenience (that of a running off the line in case of the movable rails being badly set for a train coming from the crossing) by applying to each of these rails a safety apparatus consisting of a plate connected with the rail; forming outside an ascending incline $\alpha\beta$, rising to the level of the rail, and carrying on the inside of the line, a piece of tapered rail *st*, somewhat close to the rail between *s* and *t*, and of a guard-rail *c* (Pl. XXXVIII, figs. 1 and 2).

If a train is situate on the line N° 2, in the position shown in fig. 1 (the straight line being open), the flange of the wheel A rises upon the incline $\alpha\beta$. The wheel B continues to roll on the piece of rail $s't'$, which draws it nearer to the principal movable rail, upon which of itself it comes to bear, being directed by the guard-rail c'; while A, whose flange rises above the level of the rail, and following the motion transmitted to it by its axle, passes over the rail, and then applies its tyre upon it.

It may readily be seen how this apparatus works in the opposite situation (fig. 2); that is to say, when the train is situate on the straight line, the open way being the throw-off one.

This arrangement is open to the serious objection, that it encumbers as it were the movable rails with additional weight, especially at the part where the amount of movement required is greatest; the facility of working being much impaired thereby.

Tapered points, now universally used in Europe, are not in favour in the United States; where they are objected to on account of their rapid wear (which is quite true on badly maintained lines). They are avoided by ingenious arrangements, another example of which, we will now consider.

N° 266.

Wharton switch. — Mr Wharton, an American Engineer, has devised an arrangement of points, which is much in use in the United States (*).

The object of the inventor was two-fold; to avoid the tapered switch tongue, and also to leave the main line intact, by placing the movable parts on the

(*) See the Journal of the Franklin Institute of Philadelphia, 1873, p. 1.

deviation line; or, if there be a throw off on either side, on the least important one.

This, he has succeeded in effecting, in an ingenious manner, but not, without a certain amount of complication (Pl. XXXVIII, figs. 3 and 4).

As with ordinary points, there are two switches α, α', connected together, but they are not tapered; and instead of one belonging to the straight way, and the other to the deviation line, they both belong to the latter, and are consequently placed, the one marked α inside, and the other α' outside.

When the principal line (N° 1) is open, the two switches, being away from their respective guard-rails, have nothing to do, and leave that line perfectly free for circulation in both directions. Let us now consider what takes place, when the throw off line (N° 2) is open, by placing its switches against the rails of the other line.

1° *A train coming from the common portion* (fig. 3). In order that the pair of wheels MN may reach the position M'N', it is necessary that the flange of the wheel N should pass over the fixed rail A; in order to do this, the exterior switch α', itself longer than its fellow α, has, beginning at O, a gentle incline, reaching up to and exceeding the top of the rail A; and then, by a counter incline, dropping again to its original level. The wheel N bearing, by the outside edge of its tyre, on the inclined plane Oα', passes over the rail A, then descending the counter-slope places itself in the position N'. But the wheel N', as soon as its flange has risen above A, is no longer guided and therefore does not receive any deviating impulsion; this is given to its fellow wheel M, the flange of which enters a groove or channel in the deviation switch $\alpha\alpha$, widened out.

2° *A train on the throw-off*, when open towards the common portion (fig. 3, with the arrows in the opposite direction). M' now passes to the position M on the rail of the straight line; while N', once more passing over A, presses its tyre on the continuation of this rail.

3° *A train on the straight line*, going towards the common portion (fig. 4). If it finds the switches wrongly placed, that is opening the throw-off, they, being made self-acting, are set right by the wheel M' pushing α aside, and consequently also its fellow switch α', which thereby leaves a free opening to the outside part of the tyre of N. Three guard-rails, K fixed, and K', K'', each respectively connected with the switches α,α', ensure the proper working of this apparatus. The guard-rails K, and K' in continuation of the former, when the straight line is open, complete or rather supplement, as may be required, the action of the groove of the switch α. As to the guard-rail K'', its connection with the switch α' imparts to it a motion, the opposite

of that, which the latter receives. When the straight line is open, this guard-rail recedes inwards from the rail A a distance, exactly equal to that, which α' has moved towards the outside; leaving the flange N a clear way, while also supporting that wheel. When the throw-off line is open, K″ presses against the rail A, on one side; while at the same time α' acts on the other. The flange of N thereby finds its passage closed, at the very moment when this wheel should begin to mount the incline $\alpha' o$.

When, the switches are made self-righting, as in case N° 3, the two movable guard-rails K′, K″, follow the movement of the switches; when K″ assumes a suitable position.

These additional pieces complicate the apparatus; which does not appear to offer any material advantages over the ordinary points. It may be urged, that the Wharton apparatus allows trains to be run over the main line, at a high rate of speed with greater safety. But, the crossing still exists, and it is there especially that concussions are caused by the open gaps. To be consistent, therefore, in this apparatus, the gaps there should be avoided by reverting to movable crossings (259); these have, however, with good reason been abandoned.

N° 268.

It is not uninteresting to observe, as regards shunting operations in stations on double line railways in the United States, that shunting sidings are often placed between the two principal lines; which can thus be used for either one or the other of the lines.

It is seldom, so it is said, that a train requires to be shunting in both directions at the same time. However, when the traffic is of sufficient importance to necessitate a double line, it is decidedly advisable to avoid every thing, that might interfere with the free circulation in either direction. It is also probably correct, that, for an equal sum more of these, "between line" sidings could be laid down, despite their double sets of points, than there could be of single ones. These double sidings can, however, hardly be used, except on the level.

N° 269.

Counter-balance weights for switch levers. — It is not, as is generally stated, the fact of the weight being fixed or movable on the lever, that forms the distinctive feature of the two modes of working these levers. The distinction consists in that in one case, the lever, left to itself, always opens the same line; whereas, in the other, the lever is capable of opening either line.

This latter condition in no way requires, that the counter-weight should

be movable on the lever; it might just as well be keyed on to it. It is only necessary, that the lever should assume, on either side of the vertical, two equidistant positions of equilibrium; corresponding, one to the opening of one line, the other to that of the second line. This it is, that marks the difference between the two modes of working; and whether the counterweight be fixed, or movable, is but a secondary matter.

Nevertheless, it is preferable, that it should be movable; as where there are two positions of equilibrium, it somewhat assists the passage from one to the other. With the single position of equilibrium (the other being maintained as long as required, by the counterweight being supported by hand) it is sufficient to make the counterweight fixed, by passing a padlocked pin through it and the socket also. By this arrangement the same apparatus can be made to satisfy one or other condition.

N° 275.

M. Chaperon, " Ingénieur en chef des ponts et chaussées ", says, " Trials " have been made at Paris, with cast chilled crossings, much used in Ger- " many; and known as of " Gruson metal ". They stand very well; but, " the metal very frequently peels off, and they are rather expensive. For " the present, we adhere to our crossings, fitted together, and formed of " severalpieces (282)".

CHAPTER XI.

N° 316.

In this paragraph a few remarks were made in order to point out the unfortunate conditions of the wear of iron rails; which differs greatly from that of cast steel ones, where, the deterioration is not due to local deformation or to inherent defects, but to a nearly uniform wear, which scarcely alters the form of the rolling surface, and which is slow and in direct proportion to the use made of them.

In the case of iron rails, the excess of metal, proposed to be stored in the head, is of no use as far as deflection is concerned, nor does it add to their duration; for, it is solely owing to deformation in the form of the head, that their removal is necessitated. With steel rails, however, this accumulation in the head, being a reserve of metal to counteract wear, is perfectly logical.

In the opinion of many engineers, the substitution of steel for iron may

reasonably give rise to the old contest between the two sections; the symmetrical double headed, and the flange one, and it may form a fresh argument in favour of the former. When it becomes a question of *wear* and not of *deformation*, it is difficult to see, that the advantage of having two rolling surfaces to wear out, should be greater with steel, than with iron; or in other words, why this excess of metal is better placed in the two heads than in one. Besides, it should not be forgotten, that the hammering caused by the chair, is the primary cause in the deformation of rail heads.

N° 347 and foll^s. — *On Steel Rails.*

In the year 1867, the superiority of the Bessemer steel rail, or more properly, of the cast homogeneous metal rail, was not as marked, as it now is. Considered at first, as a severe remedy applicable only in extreme circumstances at points where the causes of destruction were excessive, the cast steel rail tends daily more and more to supersede the iron one, whatever the nature of the traffic. It possesses great economical advantages, and it will doubtless retain them, notwithstanding the great exertions being made to improve mechanical puddling; not only as regards annual expenses consequent upon its lengthened life, but also, as to first cost, provided the properties of the material are taken into account in determining its form and section. To give the steel rail the same weight as the iron rail (unless the latter be too weak) becomes a misapplication of metal; the more unfortunate, the greater the mass in question. It is in fact, to commit the blunder, so justly held up against the old regulations as to steam boilers, which fixed the same thicknesses of plate, whatever its quality. The same reproach is equally applicable to the Board of Trade regulations in railway structures; which impose the same limit of strain for steel, as for the most inferior iron plates (viz 5 tons per square inch in tension, and 4 tons in compression). There is, therefore, no advantage to be gained by the use of a metal which would permit of much higher strains. "The construction of iron bridges is behindhand in England," remarks M^r Maynard, the engineer of the Crumlin viaduct, "and the fault lies with these regulations."

One of the favourite arguments of the advocates of the unequal double-headed rail was, with equal weights, the supposed extension of the life of that rail. The concentration of a greater quantity of metal in the head acted upon by the wheels, it was stated, permitted the rail to remain effective for a longer period. This is altogether a mistake, for the iron, formed of layers badly welded together, does not wear away; the head crushes, exfoliates, and the

metal peels off in strips. The necessity for replacing the rail does not arise then from loss of weight, or from ordinary and uniform wear, but from deformation, and from local excoriations in the rolling surface of the upper member.

With cast metal, however, welds are done away with, and therefore there is no unsoldering; and, unless the metal be of too soft a description and it flattens under the rolling load, it wears away without any perceptible deformation. Therefore, that, which is incorrect with iron, is perfectly legitimate as regards steel; where some metal may, and ought to be stored up in the head, and where a suitably designed section becomes easy. When new, it has an excess of transverse resistance; the neutral axis, at first above the half height, grows gradually lower in proportion as the head wears; and the rail is only replaced when its stored up metal has disappeared, that is when the neutral axis has descended to the mid-height, or even somewhat lower.

This regular progression is no hypothesis, but an actual fact. It has been observed on all the main lines of railway, where steel rails have been extensively used. A few years have sufficed, owing to the enormous traffic on certain sections, to afford enough evidence of the law of wear in rails; a law which differs, and should differ, between the several lines, as it depends with a given rail, not only on the degree of traffic, but also on the construction of the rolling stock, especially of the locomotives.

The simplest measure, and one which is sufficiently exact, of the life of a rail is the tonnage that has passed over it, up to the time when its removal becomes necessary. No doubt, the total tonnage does not include all the elements that affect the question; the wheel load, the nature of the gradients and curves, modifying to a certain extent the action of the driving wheels and that of the breaks, and again still more the question of speed, have all a direct influence.

The amount of the limit of tonnage varies greatly between one line and another, although there may be certain compensations in the matter of gradients and of speed. For the whole of a main line, the result can be, but a mean; even between one portion and another, a comparison of the limit of tonnage is far from affording the necessary elements for a legitimate classification of rails of the same section, of the same weight, and laid under the same conditions.

With iron rails of the best quality on the Northern of France Railway, the limit does not exceed 20 millions of tons, diminishing to 14 millions of tons, for rails of ordinary quality.

With steel rails, this circulation of 20 millions of tons, corresponds to a uniform wearing away of only 0·04 of an inch; it would therefore only be

requisite to provide an extra layer, $\frac{1}{8}''$ thick, in the head, to assure a life of about 200 millions of tons to the rail.

This simple proportion between the wear and the traffic is the result of experience, sufficiently extended to prove that the power of resistance to wear in the head does not sensibly diminish from the surface towards the interior.

In the Northern of France rail (Pl. XXXVIII, fig. 6), the molecular resistance, at first greater in the foot than in the head, is equal to it after $\frac{1}{8}''$ is worn away, and becomes less than it, as the wear increases. But, even with a wear of $\frac{3}{8}''$ the transverse resistance of a steel rail, weighing when new 61 lbs to the yard, but afterwards reduced to $53\frac{1}{2}$ lbs, is still higher than the original resistance of an iron rail weighing 75 lbs to the yard.

Recent experiences in England (the earlier ones have already been referred to in paragraph 353) do not appear to confirm the approximate ratio between the amount of wear and of the circulation. In a paper read by Mr Price Williams before the Institution of Civil Engineers on the 23rd May 1876, "On the Permanent way of Railways," he calls attention to the first steel rails, which were placed on the London and North Western at Camden Town in 1862, and at Crewe in 1863. In the case of the latter ones, a wear of $\frac{1}{16}''$ corresponded to an average traffic of 9,370,777 tons; while, on the Great Northern, in the Maiden lane and Copenhagen Tunnels, the same amount of wear, gave a tonnage varying between 5,251,000 and 31,061,000 tons. Other rails have been more recently placed (1866-67) near Hornsey; one of them, the only one tested, appears to have worn away, at the rate of 27,727,000 tons for every $\frac{1}{16}''$, the proportion of carbon being 0.32 per cent.

Mr Price Williams considers, that it will be possible to produce rails of a sufficiently uniform composition to eliminate the irregularities which do not result from different local conditions, and to obtain an average maximum endurance of 30,000,000 tons, for each $\frac{1}{16}''$ (that is to say, very nearly the same result as that obtained, on the Northern of France); which for the double-headed rail on the Great Northern, would give, according to Mr Price Williams, a total tonnage of 300,000,000 tons, as the average life of a steel rail, as compared with 17,500,000 tons, the average life of iron ones.

At this rate, on the most heavily worked portions of the Great Northern, the life of a steel rail would be forty-two years.

Mr Bessemer, was the first to furnish the commercial world, with iron in large quantities in a state possessing homogeneity and cohesion. As to the term "*cast steel*" it seems ill fitted to a product which, according to the use made of it, either ought, or ought not, to be steel: *steel* for rails, when in a condition to be tempered; *wrought iron* for boiler plates, which ought only to be received, when in a state unfit for tempering.

Fusion in the Siemens reverberatory furnace ensures the high temperature required, and forms another process for the production of the same substance;

a process which at first seemed as a kind of supplement to the former, by using up the waste and the rail-ends, but, which now bids fair to equal, if not to surpass it, in importance.

Objection is made to the Bessemer process, in that it almost excludes ores of medium quality. The Siemens-Martin or scrap process, owing to its reaction being slower and more easily regulated, seems much more suitable for partially eliminating the injurious components; and is consequently better adapted for the regular use of pigs of a less pure quality.

This process consists, in forming on the hearth of a reverberatory furnace, a given quantity of molten cast iron with the addition of products, containing less carbon, such as Bessemer rail ends and scrap. The carbon distributes itself uniformly throughout the mass, which is brought by a given partial oxidation to the prescribed proportion. Spiegel is finally added, or ferro-manganese, to impart to the metal its malleable character. The oxidation of the carbon without any blast, simply by the flames in a mass of fluid metal 16″ to 20″ deep, would be very slow; it may be accelerated by an addition of rich ore containing a high proportion of oxygen.

The Siemens, or ore, process, which is practised on an extensive scale in England, consists of the preparation of a bath, of say 10 tons, of pig metal on the hearth of a Siemens furnace, and in the addition gradually of about $2\frac{1}{2}$ tons of rich ore, which causes violent ebullition, and the decarburisation of the metal; cleaning it at the same time from silicon, and to some extent from sulphur and from phosphorus. This process is, amongst others, used at Landore, Hallside (Steel C° of Scotland), Dowlais, Panteg, Vickers and C° and Cammel and C° of Sheffield, at Krupp's of Essen, and other places. Metal of the higher quality for ship-building and engineering purposes is generally produced by this process. At Landore old iron rails are converted into steel rails of excellent quality.

M. Pélatan, a pupil of the school of Mines of Paris, in some interesting notes on a tour, says of the Hallside works, that the ordinary furnaces are charged with 3 tons of Scotch pig (Gartsherrie), $1\frac{1}{4}$ to $1\frac{1}{2}$ tons of steel scrap (steel which had escaped from the moulds while being run off), and 1 to 2 tons of magnetic iron from Marbella (Spain) and of hematite from Bilbao and Algeria.

The spiegel, which is added in the proportion of from 7 to 9 per cent of the charge, contains 25 to 30 per cent of manganese; it is therefore nearly ferro-manganese.

The operation lasts from 6 to 8 hours. Three charges are made, yielding from 5 to 6 tons of steel every twenty-four hours. The large furnaces, such as are now constructed, yield as much as 10 tons.

The ingots weigh from 12 cwt to 13 cwt each, sufficient for two rails. They are reheated in one of the Siemens large reheating furnaces, of similar construction to the fuzing ones, shingled by the squeezer and then passed to the blooming hammer, which produces blooms 4″ square, and about double the length of the ingot. These

blooms are reheated and roughed into the rail section by the blooming mill, the rolls of which are interchangeable.

A similar process is adopted at Landore and at Dowlais in South Wales.

In England, a decided preference seems to be given to this process over the Bessemer one, which is more exacting, as regards quality of the materials used. Many of the iron works, such as Dowlais, use both conjointly. Cast iron at times forms but a small proportion of the charge; as at Dowlais, where a very large amount of scrap iron, rail-ends, and iron filings are used. The charge consists principally of wrought iron and of steel, with a small proportion of cast iron and consequently of ore; to which is added 12 per cent of spiegel, containing but 10 per cent of manganese.

The following analyses are extracted from M. Pelatan's note-book; the two first being for steel rails by the Siemens-Martin process; and the third by the Bessemer one.

1st Hallside.

Iron	99·01	99·08
Carbon	0·48	0·39
Silicon	0·08	0·12
Sulphur	0·02	0·03
Phosphorus	»	»
Manganese	0·41	0·38
	100·00	100·00

2nd Landore.

Iron	99·125
Carbon	0·490
Silicon	0·009
Sulphur	0·041
Phosphorus	0·066
Manganese	0·396
Calcium	0·047
	100·134

The steel used for plates contains less than 0·20 per cent of carbon; for rails about 0·40, for tyres and for forgings 0·50, and for wire, according to use, from 0·30 to 1·10 per cent.

Bessemer steel from Ebbw-Vale. The resulting product at these works is of a very soft description; there is consequently a considerable amount of waste.

Iron	99·478
Carbon	0·292
Silicon	0·010
Sulphur	0·012
Phosphorus	0·061
Manganese	0·136
Calcium	0·010
	99·999

The tendency at some of the English iron works is to roll steel rails of very great length. This is not merely to reduce the number of joints, as the facilities of maintenance fix a limiting weight; and besides, these great lengths are recut : but it is also to reduce waste at the ends.

At Ebbw-Vale, and at Dowlais, bars of the length of two rails are rolled; while at Barrow, they are as much as 23 yards long.

Phosphorous steels.

Of the many substances, that enter into the composition of cast iron, phosphorus is one of the most difficult to eliminate. M. Tessié du Motay endeavoured by a previous process of purification to confine the proportion of phosphorus within such limits, as to admit of its use in the steel bath. He failed in doing so; but the experiments made by M. Euverte, and Mess^rs Valton and Pourcel at Terre-Noire (Loire), afford the promise of the regular production of a cast metal, possessing the commercial properties of Bessemer steel and yet containing a large proportion of phosphorus. This metalloid would in a great measure take the place of carbon; there would therefore be phosphorous steels, as well as carburetted steels.

The following principles have been laid down by M. Euverte, as characterizing the question as it now stands.

" 1° It is desirable, in order to obtain phosphorous steel of suitable quality, that " the amount of phosphorus should not exceed 0·35 per cent.

" In order to make it possible even to attain this limit, the amount of carbon " should not exceed the proportion of 0·15 to 0·18 per cent.

" 2° The presence of silicon, should be avoided as much as possible. In phosphorous steel, manganese on the other hand is not attended with any inconvenience; " its presence, in proportion of 0·6 to 0·8 per cent is even favourable to the quality " of the steel.

" 3° In order to obtain steel of the above quality, it is necessary to make use of " the Siemens-Martin fusion process. Care being taken in the first instance, that " the pigs used are not silicious and contain the least possible amount of carbon.

" 4° A small amount of carbon being one of the conditions essential to the success " of the operation, none should be added in any form whatever. The operation " should be carried out with ferro-manganese of as rich a quality as possible. The " admixture of 0·60 to 0·64 of manganese, which is an ordinary proportion at the " Terre-Noire works, seems to be absolutely necessary to arrive at the results already obtained, and of which experiments have afforded us specimens; the proportion of 0·64 may be exceeded and carried even to 0·80, but the cost price becomes " very heavy.

" 5° These several conditions being fulfilled, it appears evident from experiments, " that phosphorous rails can afford most satisfactorily the same power of resistance, " as may be justly required of a good steel rail.

" 6° As the result of careful and repeated experiments, it would appear, that the " resisting power of the metal increases with the amount of mechanical manipulation it has received during its several transformations.

" 7° In practice, therefore in dealing with phosphorous steels, it appears advisable, that the ingots should be of as large a section as possible in proportion to " the ultimate one."

Experiments of M. Euverte. " The Terre-Noire iron works manufacture two des-

" criptions of steel : 1° One, chiefly by the Bessemer process, composed of pure ores; " especially those from Algeria, Spain, the Island of Elba, the Pyrenees, and the " Ardèche. 2° Another, containing phosphorous ores.

" *Bessemer or carburetted steels.*

" These may be provisionally divided into three classes.

" *a.* Hard steel (for Rails, Fish plates, and Springs).

" *b.* Medium soft (for Tyres, and Plates used in Bridge Construction).

" *c.* Extra soft (for Boiler plates, Crank axles, and Machinery work)."

	LIMIT of elasticity.			BREAKING weight.			ELONGATION PER CENT bars 8" long.		
	Tons per sq. inch.		Tons per sq. inch.	Tons.		Tons.	per cent.		
Hard steels.	23·5	to	29·5	44·5	to	50·2	11	to	6
Medium steels.	19·0	to	22·9	36·8	to	43·8	18	to	12
Extra soft.	15·2	to	18·4	29·5	to	33·0	26	to	20

" These steels, of a superior quality, are principally affected, by the amount of " carbon; and also by that of silicon, of phosphorus, and of manganese. With this " class, however, it is the carbon, which has the greatest and the most character- " istic influence."

The hard steels contain	0·50 to 0·75	per cent of carbon.
The medium soft steels contain.	0·30 to 0·48	—
The extra soft —	0·15 to 0·25	—

" The silicon appears to act very much in the same way as the carbon. It hardens " the steel, but at the same it renders it more brittle; it should therefore be avoided. " By the Bessemer process, however, the steel retains, but a small portion of it, or " none at all; it is entirely consumed by the strong current of injected air. This not " being the case in Siemens-Martin process, it is therefore necessary to avoid, as " much as possible, its presence in the ores made use of.

" As regards the phosphorus, it cannot be entirely avoided; even the best Bessemer " steels contain from 0·05 to 0·07 per cent. It is allowed, that this amount has no " sensible influence on the quality of the steel; if even it does not improve its resist- " ance and power of elongation. The effect of manganese, as to which opinions are " very divided, is looked upon favourably at Terre-Noire, when the proportion does " not exceed 0·3 to 0·4 per cent with extra soft steels; with the others, it may be as " much as 0·6 to 0·7 per cent. It improves the resistance and the facility of tem- " pering (*).

(*) The proportion of carbon alone does not determine the degree of hardness of Bessemer steel. According to Mr Willis, the chemist at the Landore Siemens-Steel Works, it is the total amount of both carbon and manganese which fixes the degree of hardness.

" The question, after all, was to ascertain, whether rails of phosphorous steel, " made in a Siemens furnace, would fulfil the conditions required by the several " specifications. The rail of the Northern of France weighing 61 lbs per yard run " (Pl. XXXVIII, fig. 6) was taken as the type.

" The comparative tests were made on rails, the product of a good draw, the one " of Bessemer, the other of Siemens-Martin; containing 0·3 to 0·35 per cent of phos- " phorus, and 0·15 to 0·2 per cent of carbon.

" The following tables are taken from a paper read in 1875 by M. Euverte, before " the meeting on Mineral Industry, which took place at Terre-Noire.

A. — DEFLECTION TESTS.

1° Bessemer steel.

Rails. 61 lbs per yard run.

		BESSEMER STEEL.		PHOSPHOROUS STEEL.		REMARKS.
		Deflection when loaded.	Permanent set.	Deflection when loaded.	Permanent set.	
	Tons.	Ins.	Ins.	Ins.	Ins.	The results annexed are the means of twenty-five different draws of the converter. The rails tested were placed on two bearings 3'.3" apart. The Bessemer steel experimented upon contained : From 0·45 to 0·55 per cent of carbon, and — 0·15 to 0·25 — of manganese. with traces of phosphorus. The phosphorous steels contained : From 0·15 to 0·20 per cent of carbon. — 0·27 to 0·32 — of phosphorus. — 0·25 to 0·35 — of manganese.
Load.	12·27	·098	·000	·096	·000	
	17·22	·126	·000	·118	·000	
	19·69	·138	·000	·133	·000	
	24·60	·173	·008	·173	·004	
	29·50	·327	·126	·938	·737	
	34·44	·642	·394	1·525	1·241	
Breaking weight.		44·29 to 48·23 tons.		42·32 to 47·25 tons.		

2° Phosphorous and manganese steels.

Rails. 61 lbs per yard run.

		DRAWS N°s 1767 / 1771		DRAWS N°s 1769 / 1773		REMARKS.
		Deflection when loaded.	Permanent set.	Deflection when loaded.	Permanent set.	
	Tons.	Ins.	Ins.	Ins.	Ins.	The rails experimented upon were of the Northern of France type, weighing 61 lbs to the yard run. Draws n°s 1767, 1771 contained : Carbon. . . . . 0·17 to 0·22 per cent. Phosphorus. . . 0·25 to 0·27 — Manganese. . . 1·00 to 1·20 — Draws n°s 1769, 1773 contained : Carbon. . . . . 0·17 to 0·22 per cent. Phosphorus. . . 0·28 to 0·31 — Manganese . . 0·50 to 0·70 —
Load.	12·27	·071	·000	·074	·000	
	17·22	·091	·000	·091	·000	
	19·69	·106	·000	·110	·000	
	24·60	·138	·008	·142	·004	
	29·50	·370	·200	·493	·327	
	34·44	·943	·787	1·330	1·125	
Breaking weight.		42·32 to 47·25 tons.		42·32 to 47·25 tons.		

B. — IMPACT TESTS.

1° Bessemer steels, and phosphorous steels.

Rails. 61 lbs per yard run.

	BESSEMER steel. — Deflection under blow.	PHOSPHOROUS steel. — Deflection under blow.	REMARKS.
Ft. Ins.	Ins.	Ins.	
With a fall of 1 · 8	·032	·071	The rails referred to in this table, are the same, as those in table N° 1 of the deflection tests. The impact tests are made with a monkey weighing 660 lbs, dropping on to the middle between the two bearing points 3'·3" apart. The bearing points rest on a block of cast iron weighing 9 tons 6 cwt.
2 · 6	·063	·146	
3 · 3	·146	·296	
5 · 0	·304	·469	
6 · 6	·512	·920	
8 · 3	·955	1·337	
9 · 10	1·306	1·806	
Breaking with a fall of	12'·4" to 14'·0"	11'·6" to 12'·4"	

2° Phosphorous and manganese steels.

Rails. 61 lbs per yard run.

	DRAWS N^os 1767 / 1771 — Deflection under blow.	DRAWS N^os 1769 / 1773 — Deflection under blow.	REMARKS.
Ft. Ins.	Ins.	Ins.	
With a fall of 1 · 8	·039	·039	These are the same rails as those referred to in table N° 2 of the deflection tests.
2 · 6	·079	·099	
3 · 3	·165	·216	
5 · 0	·323	·394	
6 · 6	·547	·666	
8 · 3	·837	·986	
9 · 10	1·105	1·495	
Breaking with a fall of	9'·10" to 14'·9"	14'·9" and over.	

C. — ELONGATION TESTS.

Bessemer steels, and phosphorous steels.

	LIMIT of elasticity.	BREAKING weight.	ELONGATION PER CENT. on test bars 8'' long.	on test bars 4'' long.
Bessemer steel.	Tons per sq. inch.	Tons per sq. inch.	Per cent.	Per cent.
Test bars turned out of the head of the rail. .	24·7	49·5	7·0	8·5
— cut out from the web of the rail. . .	26·0	48·1	7·0	8·5
— cut out from plates.	23·5	45·6	9·5	11·2
Phosphorous steel.				
Test bars turned out of the head of the rail. .	24·1	33·2	9·5	11·2
— cut out from the web of the rail. . .	25·4	35·4	10·2	12·7
— cut out from plates.	21·2	36·3	17·7	21·3

These tests were made upon rails and ingots, from the 25 draws experimented upon in the form of rails.

" Here end," prudently remarks M. Euverte, " the observations which need be " made, as to the manufacture of phosphorous steels.

" The question might be dealt with in its entireness, we again remark. But the " facts already known appear to form a most interesting whole; whence may be " drawn, we conceive, practical conclusions of considerable utility."

The facts contained in the above tables are undoubtedly very remarkable. They appear to indicate, that, thanks to the Siemens-Martin furnace, the manufacture of cast steel rails, may be carried on, without, being obliged to have recourse to selected ores.

Experiments carried out at iron works, though numerous and varied, can however be but presumptions. The test of actual working is what is required.

This, is being done, on the Northern of France line, under the superintendence of M. Contamin, an Engineer, and Professor at the École Centrale, Paris. Although the results have not yet been completely developed, the following information, kindly placed by M. Contamin at the disposal of the author, shows the present state of the question, and will prove of interest.

The object of the first batch of phosphorous rails, made at Terre-Noire for the Northern of France Railway, was in order to exhibit to the engineers of that line, both the process of manufacture and its products; which were submitted at the works to the ordinary tests, and with fair results.

The rails, only eight in number, taking up the whole amount of metal run out, were laid down on 28[th] May 1874 in the Tergnier Station, on one of the main lines, where the mean daily circulation amounted to 50,000 tons; consequently a heavy one. The following was the condition of matters on the 11[th] March 1876.

RAIL N°.	DATE when first laid down.	DATE of withdrawal	NUMBER OF DAYS in use.	WEIGHT		LOSS IN WEIGHT		TOTAL circulation on each rail.	OBSERVATIONS.
				initial.	at time of withdrawal. (a)	total.	per yard run.		
				lbs.	lbs.	lbs.	lbs.	Tons.	
2	28 May 74	»	654	531·30	512·38	18·92	2·16	23,751,000	(a)
7	d°	»	654	528·00	510·40	17·96	2·01	23,751,000	(a)
12	d°	»	654	528·00	513·70	14·30	1·63	23,751,000	(a)
5	d°	11 March 1876	654	530·20	506·88	23·32	2·66	23,751,000	(b)
8	d°	7 Sept. 1875	467	528·00	514·80	13·20	1·51	16,553,450	(b)
10	d°	4 Dec. 1874	191	530·20	523·60	6·60	0·74	6,829,590	(c)
11	d°	7 Sept. 1875	467	530·20	519·20	11·00	1·25	16,553,450	(d)
6	d°	d°	467	530·20	523·60	6·60	0·74	16,553,450	(e)

(a) The rails n[os] 2, 7 and 12 are still in use and in good condition; the weights in the table show their weight on the 11[th] March 1876.
(b) Injured by blisters, which produced an enlargement.
(c) This rail was broken previous to its being laid down; probably it was let to fall, at the time of its being weighed.
(d) Injured by blisters.
(e) Injured; the foot showing indications of fracture.

These results are only fairly satisfactory; the number of defects in the rails, is relatively considerable. A wear of $\frac{1}{16}''$, corresponding to a loss of weight of $\frac{3}{4}$ lb. per yard run, by a circulation amounting to 16,553,300 tons.

Rails from the Imphy Works, heavier it is true (74 lbs instead of 61 lbs), were placed at the same spot; but they did not, after a circulation of 210,655,800 tons over them, show a wear of much more than $\frac{3}{8}''$, or 31,230,000 tons for every $\frac{1}{16}''$ of wear.

It would, no doubt, be impossible, to draw any absolute conclusions from so restricted a number of observations; yet it cannot be denied, that the result seems to be, relatively speaking, but little favourable to phosphorous rails.

Other draws, 25 in number, were made, in view of a more extended experience, in connection with Russian railways. The ingots for each operation were rolled, some for the Northern of France rail, some for that of the Russian lines, which is a little heavier (66 lbs per yard run) (*).

The number corresponding to the draw was marked on each of the rails,

(*) A lighter rail of 54 lbs was first used on the State lines, replacing an iron one of 65 lbs to the yard.

which were laid down on both lines of way. The effect upon them of such different climates will thus also be seen.

On the Northern of France, they were laid down, on the right-hand line between Ermont and Pontoise. Two rails, originally weighed with great care, are again re-weighed every six months, in order to ascertain the exact amount of wear as compared with the circulation. The engineers of that line have carefully followed the manufacture of these rails.

The manufacture of phosphorous rails, so are termed at the works, those containing 0·3 per cent of phosphorus and 0·15 to 0·18 of carbon, require special care both in heating and in passing through the rolls, which are used for carburetted rails. Up to the present time, these rails have only been made as an experiment.

The following information, as to the wear of Bessemer steel rails may be quoted from a paper "On Bessemer steel rails" by Mr J. T. Smith. M. Inst. C. E. of the Barrow Steel Works (*), read in London before the Institution of Civil Engineers.

(*) See " Proceedings, Institution of Civil Engineers ", April 6th 1875.

Results of experiments on double-headed Bessemer steel rails, manufactured at the Barrow Steel Works, in wear on the line of the Furness Railway for eight years.

N° IN Pl. XXXVIII.	STRAIN REQUIRED to punch hole ⅞ inch diameter through web ¾ inch thick.	BENDING STRAIN required to produce set. Supports 36 inches apart.	TENSILE TESTS specimens from web. BREAKING STRAIN per square inch original sectional area.	TENSILE TESTS specimens from web. ELONGATION. Length extended = 2 inches.	CARBON.	ORIGINAL WEIGHT OF RAIL per yard.	WEIGHT OF RAIL per yard after wear.	WEAR OF RAIL PER YARD.	PER CENTAGE OF WEAR.	
	tons.	tons.	tons.	per cent.	per cent.	lbs.	lbs.	lbs.		
1	46·25	19	30·91	37·5	0·28	73	63·41	9·59	13·13	Soft rails average wear 13·34 per cent.
2	46·33	19	30·08	36·5	0·28	»	63·93	9·07	12·42	
3	46·97	19	31·03	36·0	0·28	»	63·95	9·05	12·39	
4	47·18	19	31·56	35·0	0·28	»	64·84	8·16	11·17	
5	48·21	20	31·53	36·0	0·29	»	61·52	11·48	15·72	
6	48·27	20	32·85	34·5	0·30	»	63·26	9·74	13·34	
7	48·50	20	33·37	32·0	0·30	»	61·14	11·86	16·24	
8	48·86	20	33·07	32·0	0·29	»	63·11	9·89	13·55	
9	48·89	20	31·88	36·0	0·31	»	63·02	9·98	13·67	
10	49·00	20	32·33	37·0	0·29	»	62·30	10·70	14·66	
11	49·00	20	33·37	34·0	0·31	»	65·07	7·93	10·86	
12	49·07	20	32·09	37·0	0·30	»	62·34	10·66	14·60	
13	49·41	20	31·97	33·5	0·32	»	65·46	7·54	10·33	
14	49·50	20	32·75	32·0	0·31	»	64·02	8·98	12·30	
15	49·68	21	33·18	32·5	0·29	»	61·66	11·34	15·53	
16	50·00	21	33·59	36·0	0·30	»	61·61	11·39	15·60	
17	50·11	21	33·08	35·0	0·30	»	61·37	11·63	15·93	
18	50·27	21	32·67	35·0	0·30	»	62·67	10·33	14·15	
19	51·05	21	33·65	32·0	0·32	»	63·60	9·40	12·87	
20	52·50	21	33·49	32·0	0·32	»	64·00	9·00	12·33	
21	56·79	23	37·01	26·0	0·36	»	58·01	14·99	20·53	Hard rails average wear 15·18 per cent.
22	58·16	23	37·42	26·0	0·40	»	59·95	13·05	17·87	
23	58·44	23	37·93	23·0	0·40	»	63·51	9·49	13·00	
24	61·24	24	41·41	26·0	0·39	»	60·45	12·55	17·19	
25	61·34	24	39·10	22·0	0·43	»	64·24	8·76	12·00	
26	64·42	24	42·82	25·0	0·44	»	63·66	9·34	12·79	
27	65·19	26	44·00	16·5	0·45	»	63·36	9·64	13·20	
28	65·31	25	39·23	24·0	0·44	»	60·84	12·16	16·66	
29	74·50	28	45·79	3·0	0·50	»	62·68	10·32	14·44	
30	82·47	31	50·42	3·0	0·57	»	62·44	10·56	14·47	

Mr Smith has suggested in his paper, in preference to the method usually adopted of testing one or two rails only out of each lot, which he considered unsatisfactory, that, if the fish plate holes were punched by a registered punching press, an index of the real quality of each rail would be obtained. In the above table, the results of punching, as to the rails in question, are indicated in the second column.

Mr R. Price Williams, in his remarks upon this table, stated that the uncertain results, in his opinion, were not so much due to an overdose of carbon, as to the varying proportions of silicon, and possibly of manganese. The results, given in the table, pointed to an evident relation between the punching, tensile and bending strains, and the per centage of carbon in the rail (Pl. XXXVIII, *fig.* 17).

He was also satisfied that more chemical information was wanted; particularly as to the effect of manganese and silicon, for he did not think the carbon alone was the cause of extra wear.

Although, it would be out of place to further enlarge on a subject which properly belongs to metallurgy, it may nevertheless be fitting to add a few remarks as to the manufacture itself.

The Bessemer process is too well known to require any further explanation. However it may be mentioned, that, while the molten pig is, elsewhere, always made use of direct from the blast furnace, yet, in England it is generally, up to the present time at least, after a second fusion, that it is treated. It would appear from experiments made at Seraing, that the latter method is not favourable to the quality of the steel; and that its resisting power, with equal chemical components, is greater, when the pig has been passed direct from the blast furnace into the converter. This was, besides, Mr Bessemer's original idea; and one to which, it is said, he purposes returning.

Dr Siemens estimates the temperature of the bath in the Siemens-furnace at 4,000° Fahr; when, at the end of the fusion, there remains on the furnace bottom a mass of some 5 or 6 tons of perfectly fluid and nearly pure iron, covered with a layer of slag some inches thick. That gentleman has some 10 ton furnaces, yielding 20 tons of steel every 24 hours, when using pig and raw ore; and 30 tons, with pig and scrap. The productive power of this process may, therefore, stand comparison, with the Bessemer one.

The 25 draws mentioned above, were made under as uniform conditions as possible. The materials were first brought to a red heat in the Ponsard furnace: additions were then made in quantities of 4 cwt each, beginning by those containing most carbon, in the following order.

1° Charcoal pig from Solanzara, containing 0·05 to 0·08 per cent of phosphorus, and 2·8 to 3 per cent of carbon.

2° Iron rails from Creuzot, containing a large amount of phosphorus, about, 0.8 per cent.

3° Steel scrap.

4° Iron rails from Alais, only slightly phosphorous, 0·2 per cent.

No stirring is required, as the slag, which protects the bath against oxidation, ought not to be mixed up with it.

In order to ascertain the exact time for performing the last operation, the addition of the ferro-manganese, small test pieces are taken and broken on the anvil. If the grain is too fine, it is toned down by the addition of ferruginous matter. When the grain appears suitable, the ferro-manganese is then added and a fresh test piece is taken.

" These phosphorous test bars", adds the author of the report whence these details

" are gathered, " present a very peculiar, and very characteristic kind of fracture; " whereas, while the test pieces of ordinary steel for rails, show a slightly bluish " granular fracture, the phosphorous ones have a laminated appearance, as of thin " layers of schist, superposed on one another. These layers bend in parallel " curves, when the hammered test piece is placed on the anvil to be bent; the colour " of the fracture is also somewhat darker, than with the test pieces of ordinary steel " for rails."

The average composition of the 25 draws was

	Tons.	cwt.
Solanzara pig	1	13
Old iron rails from the Creuzot Works	0	16
Steel scrap and cuttings from steel rails	0	16
Old iron rails from Alais	2	9
Ferro-manganese, with 0·62 per cent	0	3
	5 tons.	17 cwt.

Mean yield from the furnace, 90 per cent.

The mean proportion of phosphorus in the materials is 0·24 per cent. Supposing that the slag absorbs but a trace, and that all is retained in the metal produced, the proportion is 0·26 per cent. Analyses, made of steels similar to those in question, give 0·25 to 0·29 per cent.

The following may be taken as the composition of the rails from the Terre-Noire Works.

Iron	98·00
Carbon	0·55
Phosphorus	0·25
Manganese	0·80
Silicon	traces
Sulphur	traces
	99·60

This does not quite agree with the principle laid down by M. Euverte, as far as the carbon is concerned, which he fixes at a minimum of 0·15 to 0·18 per cent.

Both classes of rails, the Northern of France and the Russian ones, were subjected to the tests stipulated in the specifications.

Though interesting, the author prefers waiting, in common with the engineers of the Northern of France, for the result of actual experience on the line, to reproducing them here.

Working up in the Siemens-furnace of old non-phosphorous rails. — The Terre-Noire Works use up, in making their rails, a large quantity of old matter containing little or no phosphorus; such as iron rails from Alais, from Terre-

Noire and from Horme. The Northern of France has laid down several thousand tons of these rails. Under the tests at the works they behaved, as did the carburetted steel rails; and on the line, they also seem to stand as well as do the latter.

The following, taken promiscuously, is the composition of the bath of one of the above named-charges.

	Tons.	cwt
Mixture of grey (coke) pig and white (charcoal) pig. . .	1	4
Old iron rails from Horme, Terre-Noire, and Alais. . .	2	7
Steel scrap.	2	7
Spiegel, with 15 per cent of manganese.	0	8
	6 tons.	6 cwt.

The rails thus composed contain but 0.1 to 0.15 per cent of phosphorus, and somewhat less carbon than do Bessemer rails. It is therefore an intermediate product, between carburetted and phosphorous steels."

Attempts have recently been made at the works of the Russian Railway Company at St Petersburg to convert old phosphorous iron rails, as well as old steel ones, into steel rails, by means of ferro-manganese. The ferro-manganese contained 44 per cent of manganese. The results of these experiments are not known to the author, but they appear to have been very satisfactory.

The question of the conversion of iron rails, which the converter can only effect in small proportions (351), seems therefore now to be solved by the use of the Siemens-furnace; which is indeed, an important fact.

If the manufacture of cast rails could be freed from the necessity, now telling heavily against the converter, of especially using ores of a superior quality, and if it could, above all, utilize a large proportion of the phosphorous ores, so widely distributed, it would unquestionably be a great step in advance. The question is essentially one of economy. Even, a somewhat inferior quality might be tolerated, especially as to greater wear, provided it resulted in a proportionate economy.

Experience fully confirms the fact, stated long ago, that, in order to obtain steel with all its properties inherent to it, the ores used must be pure and contain sufficient carbon.

With rails this perfect condition is not absolutely necessary. Homogeneousness, sufficient hardness and resisting power, and the facility of being tempered, are alone essential for them. If experience should prove, that under the conditions which rails ought to fulfil, the limiting proportions of foreign substances are not absolute, but are bound together by certain

relations, such as a sort of equivalent between the carbon and the phosphorus, and also, that this latter, the bane of metallurgists, might actually become an aid in the manufacture of rails, it would be a remarkable fact; though one, which has to a certain extent been proved with regard to iron rails.

According to the S[t] Petersburg Journal of the Ministry of Ways and Communications, Bessemer steel is more sensitive than is wrought iron to the action of cold; the influence of which is, besides, in proportion to the degree of purity of the metal. The purer it is, the less are its tenacity and its elasticity affected by cold. On the line from Moscow to Nishni, there has been but one rail broken of those made from Siberian iron, which is very pure and soft; whilst accidents from this cause are frequent with medium quality of iron, and still more so with steel. This opinion as to the greater sensibility of steel to cold, does not accord with that of the United States engineers (354), who from their position are evidently very competent to form a judgment on the matter.

In Germany, the attention of railway directors has been drawn to the frequent breakage of steel rails, whilst being unloaded; which is of rare occurrence with iron ones. The "Geschaftsführende Direction" thinks these fractures seem to indicate, that the steel has not been suitably treated; neither in the manufacture of the rails, nor in their subsequent manipulation. It considers, that unloading ought to be performed with great precaution; although even to throw the rails violently out of the trucks had been previously recommended. This looked like a sort of supplementary test.

It is consoling, however, to find that a steel rail may, after a short period of service, thus acquire an immunity from fracture. It either possesses it from the first, or not at all.

In conclusion, the following extract from a recent paper written by M. Boussingault, on the conversion of iron into steel, may be quoted.

"I have had, as may be well imagined, many difficulties to overcome; but I can "state, that the greatest of all, has been to measure the iron, with a precision similar "to that always attainable with carbon and with silicon.

"The exact admeasurement of the iron becomes indispensable in all analyses of "cast or wrought iron, or of steel. I have been able to measure the iron to within "0·0015 or 0·003 of a grain.

"The result of the whole of the experience, as well as of the analyses, mentioned "in my paper show, that cast steels of superior quality are in reality composed of "wrought iron and carbon. As the quality improves, so does the silicon decrease "and disappear.

"These qualities are generally free from phosphorus, while manganese, as also "silicon, scarcely ever enters into their composition in a higher proportion than "0·1 per cent."

In other words, that the conditions of the true type of steel remain unchanged, and precisely the same as metallurgists have always described them.

If the presence of substances, entering ordinarily into the composition of iron, still leaves to the product properties sufficient for certain applications, it always deprives it, at least partly so, of the qualities generally sought for in what is understood by steel, properly so called.

That it is somewhat difficult to define what is "steel" may be seen from the following opinions, which were elicited during the discussion of a paper "On the manufacture of steel" by Mr Wm Hackney, before the Institution of Civil Engineers, in London, in April 1875 (*).

Mr Hackney himself considered steel, to be "any variety of iron, or alloy of iron, which is cast, while in the liquid state, into a malleable ingot". Dr Percy thought, that steel was a metal in which iron was the chief constituent, and which would harden. Dr Siemens suggested, that it would almost be impossible to define steel by its mechanical qualities; as, according to the different modes in which it was treated, it was by one mode almost the hardest substance in nature, or in another the most elastic of metals, or by a third nearly the most ductile. He proposed as a definition, "that steel was a compound of iron with any other substance which tended to give it superior strength". This would, he said, embrace the different kinds of steel, and include those compounds in which manganese, tungsten, chromium, phosphorus, or sulphur, replaced the carbon of ordinary steel.

Sir Joseph Whitworth has also proposed to define steel (**) according to its two principal qualities, tensile strength and ductility; assigning one number to each, and both combined expressing the quality of the steel. Thus, tensile strength 40 tons, ductility 32 per cent, would represent a quality of steel suitable for boiler plates, or railway wheel-tyres; while 68 + 10 would indicate another kind, suitable for boring tools.

Poncelet, and also Mallet, had likewise made suggestions of a somewhat similar character.

M. Adolphe Greiner, of Seraing (***) has classified the irons and the steels, according to their proportion of carbon, in the following manner.

(*) See "Proceedings, Institution of Civil Engineers." April 6th 1875.

(**) See "Proceedings, Institution of Mechanical Engineers", 1875, p. 269.

(***) See "Journal of the Iron and Steel Institute", 1873, p. 499.

PER CENTAGE OF CARBON.			
0 to 0·15	0·15 to 0·45	0·45 to 0·55	0·55 to 1·50 or more.
SERIES OF THE IRONS.			
Ordinary irons.	Granular irons.	Steely irons, or puddled steels.	Cemented steels. Styrian steel.
SERIES OF THE STEELS.			
Extra-soft steels.	Soft steels.	Half-soft steels.	Hard steels.

N° 357.

This paragraph contains some forms of specification for the supply of steel rails; originally, though not now exclusively, intended for Bessemer ones. As it is advisable, especially for foreign engineers, that this work should contain contracts of the most recent date, some examples are given in the following pages. The Northern of France specification is copied *verbatim*, as well as that of the Madras Railway.

The Northern of France Railway.

—

SEPTEMBER 1875.

ART. 1.

" *Object of the specification.*— The present specification is for the purpose of sup-
" plying rails in cast steel.

ART. 2.

" *Gauge and Weight of rails.*—The rails are to be of the American pattern termed
" 'Vignoles.' They shall be of the exact form, as the stamped standard gauge, to be
" supplied to the contractor. The section must be strictly adhered to throughout
" the entire length of the rail, and particularly at the ends; care being there taken
" that no compression or alteration of the form should result from cutting off the
" ends.

" To allow for the wear of the rolls and any variation in their tightening, a margin
" of 0·02″ (0m·005), either in deficiency or in excess of the transverse dimensions,
" shall be permitted : but the section must always be symmetrical.

" The rails, which do not, within the above limits, exactly correspond to the
" gauge, shall be rejected.

" The definitive normal weight per metre run of rail, shall be regulated by the first
" delivery of one hundred rails, in every respect of the exact section of the gauge.
" An allowance of 2 per cent of excess and 2 per cent of deficit is henceforth permit-

" ted upon the normal weight for all partial deliveries; below this allowance, they " will be rejected; above it, they will be accepted, but the excess of weight will not be " paid for to the contractor. Any excess over one per cent, in the total weight of " the delivery over the normal weight, shall not be paid for to the contractor.

ART. 3.

" *Length of the rail.*—The normal length of each rail shall be 26'.3" (8^m); for a por- " tion of the contract not exceeding one tenth, which shall be determined by the " Engineer in chief of the Company, the rails shall be cut to a length of 26'·0" (7^m). " Finally, in order to facilitate the manufacture, a portion of the contract, which " according to the requirements of the Northern of France Railway Company may " vary between $\frac{1}{13}$ and $\frac{1}{20}$, can be delivered in lengths of 23'·0" (7^m), of 19'·6" (6^m) " and of 16'·6" (5^m), and a portion of the lengths used in crossings; but in proportional " quantities as required in each case.

ART. 4.

" *Factory Mark.*— The rails shall be clearly marked in relief, setting forth the " name of the works, the year and the month of their manufacture. These marks " to be stamped by a groove in the last finishing roll.

" An additional mark, towards the upper extremity of each rail, stamped by hand, " shall indicate the number of the charge and the description of the steel, correspond- " ing to the ingot, whence it has been rolled.

ART. 5.

" *Quality of the materials for the manufacture of the rails.*—The rails are to be of " cast steel, manufactured entirely by the Bessemer process; or by any other sanc- " tioned by the Company.

" This shall be carried out, so as to ensure hard and tenacious steel. The texture " shall be of a fine grain and compact; it shall also show fibrous fracture, and shall " be perfectly homogeneous.

" The steel shall be run into ingots of a rectangular section, the edges being round- " ed off, to be $8\frac{5}{8}$" by $8\frac{5}{8}$"; or they may be cylindrical, $9\frac{3}{8}$" diameter.

" The weight of one of the ingots shall exceed that of the manufactured rail by, at " least the weight corresponding to the length of a lineal metre of the rolled type " rail. The fracture shall be free from ali blisters.

" The ingots are to be carefully examined; those having blisters, impurities, or " other defects, which would not disappear in the rolling, are to be rejected. Sunken " parts, and irregularities on the edges, are to be chipped off with the greatest " care, over a surface sufficiently wide to render impossible, the superposition of " the edges of those cavities, when running through the rolls.

" The agents of the Company are to have the right to demand, to be shown the " results of the tests pieces, taken at the time of the running of the ingots used " for the rails, made under their supervision.

" The rails that show layers doubling over one another, or with breaks interven- " ing, shall be rejected. Raised parts or swellings can only be allowed, when they

" are so small as not to affect either the section or the resistance of the rails; always " on condition that, after being examined by the agent of the Company they shall be " carefully rounded off with a cold chisel, and filed smoothly with a fine file, in his " presence.

" All other manipulations, either when cold or heated, are strictly forbidden.

" All rails that do not fulfil the above stipulations are to be rejected.

ART. 6.

" *Dressing and straightening the rails.* — The rails to be dressed on all four faces " with the greatest possible care; the straightening is to take place as much as possi- " ble while still hot, so soon as the rails have left the rolls. If to further perfect " them, it should be requisite to operate upon them when cold, this must be done " by pressure and without concussions, so as to avoid all fissures in the web of the " rail; the foot, meanwhile, being protected by guards of suitable form.

" The rails shall be cut off at both ends, as much as possible while still hot from " the rolls, by a circular saw, without being reheated, and a sufficient distance from " the rough ends, so as to ensure a perfect rail. The rail shall be brought to its finish- " ed length by means of a face tool, or by any other means giving an equally per- " fect result. The sections thus obtained, shall be perfectly smooth and at right " angles to the centre of the rail.

" All irregularities on the edges of these sections shall be chipped with a cold chisel, " and filed down; under no circumstances shall hammering down be allowed.

" In no case will it be allowed to reheat the ends, so as to saw them off or shear " them.

ART. 7.

" *Making the holes and the notches in the foot.* — The rails for the open line are to " be drilled and notched at their ends, according to the template to be supplied to " the contractor. For exceptional lengths, the special instructions to be followed " will be given with the order.

" The holes in the web are to be drilled perfectly cylindrical, agreeably, to the diam- " eters and directions supplied. All burrs on the holes are to be removed with the " file; no variation in the indicated position of the holes beyond 0·02″ (0^m·005) will be " allowed.

ART. 8.

" *Verifications and Tests.* — The rails to be classified with care at the works, in " series of one or more days manufacture. The agents entrusted with the reception " are to select from each series, a certain number of rails, not exceeding 2 per cent, " which are to be submitted to the following tests.

" *a. Pressure Test.*

" Each of the rails placed upright on two bearings points, 3′·3″ apart, is to be ca- " pable of bearing for a period of 5 minutes in the centre between the supports."

"1. Without retaining any permanent set after the test :

	Tons. cwt.				
A pressure of	19 · 14	for rails of	76 lbs	per yard run.
	18 · 4	—	71	—
	16 · 14	—	61	—

" 2. Without exceeding a total deflection of 1" :

	Tons. cwt.			
A pressure of	34 · 9	for rails of	76 lbs	per yard run.
	32 . 0	—	71	—
	29 · 10	—	61	—

" The pressure may be afterwards increased to fracture.

" *b. Impact test.*

" Each of the two halves of the broken rail, placed upright on the two bearings, " 3'·7" apart, these being fixed on two cast iron anvils weighing 10 tons each, which " are themselves placed on a mass of brickwork 3'·3" high, and having a bearing " surface at the base of 36 square feet, should be able to sustain without fracture the " blow of a ram weighing 6 cwt, dropping freely on the rail at the centre between " the bearers,

From a height of	8' · 3"	for the type rail of	76 lbs	per yard run.
—	7 · 9	—	71	—
—	7 · 4	—	61	—

	DEFLECTION.					
FALL OF......	ft. ins. 3 · 3	ft. ins. 5 · 0	ft. ins. 6 · 6	ft. ins. 7 · 4	ft. ins. 7 · 9	ft. ins. 8 · 3
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
For the 76 lbs rail....	·039	·118	·236	»	»	·439
— 71 —	·039	·138	·296	»	·472	»
— 61 —	·079	·197	·439	·630	»	»
An idea can be formed of the degree of elasticity of the rail from the amount of rebound of the ram.						

" If one of the tested rails, fracture below 8'·3" in the case of the 76 lb rail, 7'·9" for " the 71 lb rail, or 7'·4" for the 61 lb rail, the tests are to be continued on a greater " number of rails; and, if more than one tenth of the rails tried do not stand the test, " the whole of the series whence these rails were taken shall be rejected.

" The Company may, moreover, prescribe and have carried out at the works any " other tests that it may consider necessary, to satisfy itself of the quality of the rails; " and especially as regards tensile tests, in order to determine the resistance of the " metal and the amount of elongation at fracture.

" The bars or strips used for these tensile tests, shall be cut out when cold, in " accordance with the instructions given by the agents of the Company, from rail " ends, or from those rails which have been used in the impact tests.

" These several trials shall be made by both parties, and the results shall be stated " in a report, to be signed, both by the Company's agent and by that of the con- " tractor.

ART. 9.

" *Provisional Reception.*— One or more of the Company's agents shall undertake, " this provisional reception at the works. It will take place as frequently as possi- " ble, in proportion as the rails are manufactured; its object being to select, weigh, " and stamp all rails, that have complied with the stipulated conditions.

" The erection of the testing apparatus, as also all labour, connected with recep- " tion and the tests, which may be considered necessary for ascertaining the quality " of the steel, shall be at the expense of the contractors.

" The accepted rails shall be marked at both ends; those rejected shall also be " marked at both ends, and between the factory marks, with a special, well defined " and indelible mark, so that they may not be again presented for reception.

ART. 10.

" *Length of Warranty.* —The contractor is to guarantee the rails for a period of six " years, dated from the time of their manufacture; whether they be used at rail-cross- " ings or on the open lines.

" All rails that may during this period break or become deteriorated, otherwise " than by regular wear, are to be replaced by the contractors. The exchange of dam- " aged rails, for new ones, shall take place at the spot, mentioned in the contract.

ART. 11.

" *Right of supervision at the works.*—The contractors are to give free access to " their works, to the Engineers of the Company or to their agents, who may attend " and watch both day and night the several operations connected with the manufac- " ture of the rails, and who shall be allowed to make all necessary verifications, in " order to satisfy themselves, that all the stipulations of the present specification " have been carried out.

ART. 12.

" *Responsibility of the contractor.*—The inspection exercised by the Engineer of " the Company or by his agents, at the contractor's works, the verifications and tests, " as well as the partial reception of the rails, shall in no case have the effect of dimin- " ishing the responsibility of the contractor; which shall remain full and entire, " until the time of expiration of the warranty referred to in art. 10.

ART. 13.

" *Prohibition to sublet the contract.*— It is expressly forbidden to the contractor to " underlet to any sub-contractor, or to have manufactured at any other works than his " own, any portion whatever of the contract to which this specification refers; unless " with the express sanction, formal and written, of the Company.

ART. 14.

" *Deviation from the clauses and general conditions.* —The contractor is to be sub-

" ject, except through modifications or alterations resulting from this contract, to " the general clauses and conditions imposed on contractors of works, in connection " with the Northern of France Railway Company; drawn up on the 8th November " 1863 by their Chief Engineer, and approved on the 10th of the same month by the " Committee of Directors of the said Company.

" Any deviation from the present specification, or from the clauses or the general " conditions, will only be allowed, if prescribed or authorized by a written order from " the Chief Engineer to the Company; which the contractor will have to produce " when required of him. "

Eastern of France Railway.

The latest specification of this Company for steel rails is very similar to that of the Northern of France.

The following are the tests required.

" *Verification and Tests.*—The rails are to be carefully sorted into lots at the works " every one or two days, as manufactured. The inspectors entrusted with the recep- " tion shall select from each series a certain number of rails (at most 1 per cent), in " order to submit them to the following tests.

" Each of these rails placed upright on two bearings, 3'·7" apart, must sustain for " 5 minutes at the centre between the bearings,

" 1st Without retaining any sensible permanent set after the test,

	Tons. cwt.	
A pressure of.	18 · 4	for the 73 lbs per yard rail.
	17 · 10	— 61 —

" 2nd Without exceeding a deflection of 1",

	Tons. cwt.	
A pressure of.	32 · 10	for the 73 lbs per yard run.
	29 · 10	— 61 —

" The pressure may be afterwards increased until fracture takes place.

" Each of the two halves of the broken rail, placed on two bearers 3'·7" apart, " which are to be fixed on an anvil-block, weighing 10 tons, must bear, without " fracture, the blow from the fall of a ram weighing 6 cwt, falling on the bar at the " centre between the two bearers; viz :

From a height of 7'·10" for the 73 lbs rail.
— 7· 6 — 61 —

Under the following successive falls of.	ft. ins. 3 · 3	ft. ins. 5 · 0	ft. ins. 6 · 6	ft. ins. 7 · 6	ft. ins. 7 · 10	
	Ins.	Ins.	Ins.	Ins.	Ins.	
The indicated deflection must but slightly differ from. .	·039	·131	·276	»	·470	for the 73 lbs rail.
	·039	·137	·315	·508	»	— 61 —

" Should any one of the tested rails break under a fall of less than 7'·10" for the " 75 lbs rail, or of 7'·6" for the 61 lbs rail, or should it, under the fall above named, " retain a permanent set, exceeding by 0·079" the deflection indicated in the table, the " tests shall be continued on a greater number of rails; and, if more than a tenth of " the tested rails should not stand the trials, the whole series from which these rails " were taken shall be rejected. "

Madras Railway.

By the courtesy of the Engineers of the Madras Railway, Mess[rs] Hawkshaw, Son, and Hayter, the following specification for steel rails is here published.

The rail required is a flange rail, weighing 85 lbs to the yard, it is a little over $4\frac{7}{8}$" deep, $2\frac{1}{2}$" across the head, and with a flange 6" wide. This extra width, being in order to allow of $\frac{13}{16}$" holes being drilled in the foot, every 24" alternately on each side.

Among the tests required in the specification are two bearing upon the influence of these holes upon the strength of the rail.

SPECIFICATION FOR STEEL RAILS.

JUNE 1876.

" The following is the work required:

Steel rails	lineal feet, weighing.
Approximately	tons.

" The total length of the rails, and not the weight, is to be taken as the quantity " required.

" The general dimensions and details of the rails are shown on the sketch.

" Templates of the rails, will have to be provided by the contractor for submission " to the Engineers, which must be approved by them before the work is commenced.

" The weight of the rails is intended to be 85 lbs per yard; no rail weighing less " than 84 lbs per yard will be accepted, and no allowance will be made for any excess " above 86 lbs per yard.

" The length of the rails is to be 20 feet; but for the convenience of the manufac- " turers a quantity, not exceeding 5 per cent, will be received measuring 16 feet; it " being understood, however, that the shorter rails are to be cut from longer ones " found imperfect at the ends.

" Any rails, which require to be shortened or reduced to the length of 16 feet, are " to have the operation performed when the rail is cold; as no reheating will be " allowed.

" A measuring rod, supplied by the contractor, will be set out by the Engineers " with marks indicating these exact lengths, and on either side of this mark, and

" $\frac{1}{16}$th of an inch distant therefrom, there will be another mark; and no rail will be " accepted that is not within these limits.

" The contractor must give the Engineers one week's notice in writing previous to " any of the work being ready to undergo inspection.

" A piece of the steel rail, measuring about 4 ins. in length, and planed and fin- " ished accurately square at one end, is to be sent as a specimen to the Engineers for " approval, and the bulk of the work must not be commenced before their approval " is obtained; it is however to be expressly understood, that such approval is not in " any way to relieve the contractor from any of the conditions or stipulations con- " tained in this specification.

" The steel rails are to be manufactured from Bessemer steel; and such mixtures " of metal must be used in the convertor as will ensure the very best quality of this " class of steel. The ingots when cast must not have a less sectional area than " 100 square inches, to ensure a proper amount of work being put upon them, before " they arrive at the finished size of the rail; and a preference will be given to those " manufacturers who employ gas furnaces similar to those known as " Siemens", " where the metal is not in contact with the impurities given off by the coal during " combustion.

" The quality of the finished rails, as regards toughness combined with hardness " and strength, is to be such as shall be satisfactory to the Engineers. The rails " must be of uniform section throughout, and perfectly true to the template. They " must be straight, sound, free from splits, cracks, flaws, scoria, imperfect welds, or " defects of any kind; and the ends must be cut perfectly true and square.

" The rails will be required to have two round bolt holes $1\frac{1}{4}''$ diameter, made at " each end for fishing plates; and holes, $\frac{13}{16}''$ diameter, for fang bolts in the flanges. " These holes must be clean, without burrs on either side, and square through the " rail; and placed exactly in the positions shown on the sketches.

" Any variations from the positions, or from the correct sizes of the holes, will " render the rail liable to rejection. All the holes are to be drilled.

" The Engineers, or their authorized deputy, will from time to time select a cer- " tain number of steel rails; which must be of such strength and possess such other " qualities, as will enable them to stand the following tests.

" *First Test.*—A whole rail, undrilled, being supported on bearings 3 feet 6 inches " apart, a mass of iron one ton in weight, with a striking surface rounded to a " radius of 12 inches, will be let fall through 20 feet; and the rail must stand two " such blows without showing any external marks of fracture, though bending.

" *Second Test.*—A rail of the full length, drilled in accordance with the specifica- " tion, and supported on bearings 3 feet 6 inches apart, having one of the drilled " holes midway between the bearings, a mass of iron, one ton in weight as before, " will be let fall through 6 feet upon the centre of it; and the rail must stand two " such blows without showing any external mark of fracture, though bending.

" *Third Test.*—Each piece of rail being placed on supports 3 feet 6 inches apart, " with a hole midway between the supports, as before, a load of 35 tons will be sus- " pended from the middle; which load it must carry for thirty minutes without " showing any sign of fracture.

" If in the foregoing tests a single rail be found defective, then the tests are to be " extended to double the quantity; and, if one per cent be found defective, then the " whole lot to which the defective rails belong will be rejected.

" The Engineers retain the power to alter any of the foregoing tests; and the rails " must stand such other tests as they may consider to be satisfactory. Should the " rails selected fail under any of these tests, the Engineers shall have the power of " rejecting the whole lot to which they belong; unless it shall appear to the Engin- " eers from repetition of the trials, that the rails first selected did not fairly repre- " sent the character of those from which they were taken.

" Each rail is to be stamped distinctly in suitable characters, as the Engineers " will direct, with the maker's name or initials, the year of manufacture, the initial " letters, M. R. C., of the Railway Company, and the word " Steel. "

" The contract is to be executed in every respect to the satisfaction of the Compa- " ny's Engineers, who shall have the power of rejecting any rails, they may disap- " prove, and whose decision on any point of dispute that may arise in reference to " this contract shall be final and binding on all parties. They will also, if they think " fit, appoint a person to inspect the entire manufacture and to see that the pre- " scribed conditions are complied with; and any departure from these conditions or " any refusal to allow sufficient inspection will subject the contractor to the rejection " of the whole of the rails, and to have the contract taken out of his hands

" No rails will be considered as accepted by the Company, until the Engineers " shall have given their written certificate that they are satisfactory; but if defective " they will be liable to rejection even after they have been certified or received into " the possession of the Company, but not after actual shipment to India.

" The contractor is to provide without charge all apparatus, labour and assistance, " the Engineers or their deputy may require for testing or gauging the rails.

" The contractor must not assign or sublet the contract or any part thereof, nor " allow any portion of the work to be done, other than in his own and in one estab- " lishment, without the express written consent of the Company being first ob- " tained.

" The rails are to be delivered free on board vessel, lying in any dock or lying " alongside any wharf or in any part of the stream, at either of the ports of London " or Liverpool, as the Company may require.

" The contractor is to replace, at his own cost and charge, all rails, that may be " bent, broken, or damaged in carriage or delivery, or otherwise, previously to their " coming into the actual possession of the Company.

" The whole of the rails are to be delivered within... weeks from the date of the " acceptance of the tender.

" In the event of any delay taking place in the delivery, the Company shall be at " liberty at any time to declare the contract at an end; in which case they shall be " liable to pay only for such rails, as shall have been delivered and certified by the " Engineers as being correct and satisfactory, deducting any loss, or damage sus- " tained by reason of the breach of the contract."

. . . .

The Midland Railway, in their specification for steel rails, double headed 83 lbs to the yard, require the following tests.

" Each rail shall be capable of sustaining a weight of 20 tons applied frequently in " the centre of the bearing, without injuring its elasticity or producing a perma- " nent set; and also shall be capable of resisting, without fracture, 3 blows of a ram " weighing 20 cwt falling from a height of 12 feet on the centre. The bearings to be " as follows : for rails, having a section equal to a weight of 83 lbs per yard, the " bearings to be 4 feet (and for rails weighing 70 lbs per yard the bearings to be 3 feet " 4 inches)."

The London and North Western Railway, in their requirements for a Bessemer steel "bull headed" rail, 84 lbs to the yard (practically the same as the Midland one just named), state:

" The rail must stand without breaking two blows of a one-ton weight falling " 30 feet on to the centre of a rail, placed head uppermost on supports three feet " apart; or an equivalent test approved by the Company's Engineer."

In a paper, addressed to the Society of Civil Engineers of Paris, August 4th 1876, M. Marché remarked, that consumers of rails are not agreed as to the nature and properties of steel, although required for precisely similar purposes; "which," he says, "often occasions difficulties to manufacturers, and " acts as an obstacle to the reduction in the price of rails."

It does not follow absolutely, that, because the rails are devoted to the same purpose, they should possess exactly the same properties. With rails, or with tyres, for instance, it is fracture especially that should be guarded against. In a severe climate, softer metal may be required than in a mild one. The remarks of M. Marché, restricted as they are to French Railways, are however, quite correct; and the wish he expresses to see uniformity established, after a thorough discussion of the subject, is well advised.

" (*) Amongst engineers there exists considerable difference of opinion as " to the value of the impact test for rails; much variation also occurs in the " application of it. As the requirements, on this head, of several leading " railway companies, both in England and on the Continent, have just been " quoted, it will be interesting to endeavour to compare them together; so as " to ascertain and bring out the relative value of each of them.

" The varying elements in the several tests are, the weight of the falling " mass, the height through which it falls, and the distance apart of the " supports on which the rail is placed.

(*) Translator's remarks.

" The relative value of the two former may be expressed by the momentum " of the falling mass at the instant of impact; which is given by the well known " formula of falling bodies, $v = \sqrt{2\,gs}$. The product of this by the span, l, " gives the bending moment, M, of each mass upon the rail; whence " $M = \sqrt{2\,wh} \times l$, which will afford a means of comparison between the " different tests. Those rails which are about the same weight are grouped " together, to further aid in this result.

" Thus, taking the

		lbs.		cwt.		feet.		feet.	
" London and North Western	bull-headed rail. .	(84),	with	20	falling from	30;	supports	3	apart.
" Midland,	double-headed . .	(83),	—	20	—	12;	—	4	—
" Madras,	flat-bottomed . .	(85),	—	20	—	20;	—	3·5	—

" We have

		Momentum. Tons.		Feet.		Bending Moment. Foot-tons.
" L. and N. W. .	$\sqrt{2 \times 1^{t} \times 30'} =$	7·75	$\times$	3·0	$=$	23·25
" Madras.	$\sqrt{2 \times 1^{t} \times 20'} =$	6·33	$\times$	3·5	$=$	22·16
" Midland. . . .	$\sqrt{2 \times 1^{t} \times 12'} =$	4·90	$\times$	4·0	$=$	19·60

" And again,

" Midland (70^{lbs}).	$\sqrt{2 \times 1^{t} \times 12'} =$	4·90	$\times$	3·3	$=$	16·17
" Northern of France (71^{lbs}). . .	$\sqrt{2 \times 3^{t} \times 7'{\cdot}75} =$	2·16	$\times$	3·6	$=$	7·78

" Also, we have

" Northern of France (76^{lbs}). .	$\sqrt{2 \times 3^{t} \times 8'{\cdot}25} =$	2·23	$\times$	3·6	$=$	8·03
" — — (61^{lbs}). .	$\sqrt{2 \times 3^{t} \times 7'{\cdot}08} =$	2·06	$\times$	3·6	$=$	7·42

" This rough comparison of the various tests, estimated in a form com- " mon to all, shows at a glance, not only the relative intensity of each; but " it also points out very clearly how marked is the difference between the " requirements, in England and in France.

" In the latter country, in addition to the light impact tests, is imposed a " limit of deflection : the tendency thereby being to discourage ductility, in " favour of hardness in the steel.

" While in the former, the intensity of the impact test necessitates consid- " erable ductility (i. e. softness) in the rail, at the expense of its hardness (i. e. " brittleness) : sometimes, though not generally, are limits of deflection " imposed.

" So far experience tends to show, that in the *steel* rail hardness in the rolling " surface is not wanting; but it is ductility rather which may be deficient. " Besides it is not always the hard steel rails which wear the best; as has been " seen already (p. 524)."

N° 360.

Two test pieces, taken from Bessemer rails, manufactured by the Pennsylvania Steel Company at Harrisburg, in the United States, yielded to tension, one to a strain of 52 tons. 6 cwt. per square inch, the other to a strain of 58 tons. 6 cwt. per square inch. The elongations at rupture were not noted. In the second specimen only, the more ductile, the section after rupture was taken, it was reduced to 0·728 of the original one.

N° 366.

A commission formed in 1873, at Berlin, and composed of Government Engineers and Engineers belonging to the Railway Companies, was instructed to inquire into what measures were suitable to increase safety in the working of Railways.

The following form some of the recommendations, made after a careful investigation by that commission; at least, those which relate to the permanent way.

1° *Type of rail.*—Some of the members endeavoured to revert to the subject of the advantages of the chair system; but the commission decided almost unanimously, that the superiority of the flange rail was too well established and too little disputed, except in England, to be again discussed. It consequently decided, formally, against any fresh experiment with the chair system; adding, "that it would be a retrograde movement." The usual height given to rails, $5\frac{1}{8}''$, was considered suitable; there being no reason to increase it, at least, with the fastenings in use at present.

2° *Nature of rail.* — That Bessemer metal (*) is the best. The commission recommends that rails be tested, not only by statical tests, but also by impact; also to try their hardness with a file, and to obtain by means of curving rollers and not by screw pressure (much less by impact) the curvature necessary in sharp curves. It forbade the foot of the rail to be notched, as also punching the fish-plate holes. It strongly condemned the steel-headed rail (a form still persevered in at several works in Germany), on account of the defective welding between the steel and the iron.

3° *Cross-sleepers.*—They fix their minimum length at 8′·3″. Oak is preferable, especially in sharp curves; fir should not be abandoned, but then "a sufficient number" of bed plates becomes necessary, especially in curves.

(*) It is with iron rails, clearly, that the Bessemer rail is compared; the commission never intended to assert the superiority of the Bessemer rail, over those obtained by other processes; especially by the Siemens-Martin process.

4° *Iron bed plates on cross-sleepers.*—These are recommended, in principle, as an effective means of counteracting the widening of the gauge, and of preventing from the rail sinking into the sleepers. The commission, though it considers that one to every sleeper would be excessive, yet bearing in mind several cases of running off the line, which have occurred on straights, is of opinion that their uses should not be restricted to sharp curves only.

5° *Fish plates.* — It is useful to increase the resistance at the rail-joints, especially by bringing up the top of the inside fish-plate, as high as the free passage of the wheel-flanges will allow. Yet, similarity in the two fish-plates is advocated by many. The commission considers on the whole, that there appears to be no decisive argument to lead to a departure from the ordinary method of fishing.

6° *Fastenings.* -- Wood screws are recommended, as probably preferable to spikes; which are more used in Germany.

7° *Iron cross ties between the rails.*—Iron tie rods, used on some railways to connect directly the two lines of way, found but few advocates; nevertheless, it was deemed useful to continue the trial of them in curves.

8° *Metallic permanent way.* — The application of the Hartwich system, on the heavily worked sections of the Rhenish railway, was deemed from experience not to have proved successful. As the rail rapidly deteriorated by the flattening of the head; while its renewal was difficult.

The Hilf system (Pl. XXXVIII, fig. 12 to 14) seemed up to the present time, to be that which had answered best. A sleeper at the joint appeared useful; when some of the connecting ties might in consequence be dispensed with.

(This last recommendation of the commission, it will be seen, has been already referred to at p. 212, and also at p. 501.)

REMARKS OF M. NORDLING.

The opinions of a person, especially devoted to any particular subject, after the perusal of a work treating upon it, are of special interest; whether they are confirmatory or otherwise of the views expressed in the work. It is therefore with great pleasure, that the author has here reproduced a few comments on some of the preceeding pages; which M. Nordling, formerly Engineer in Chief of the Central Section of the Orleans Railway, has kindly sent him.

It would afford the author a similar gratification, to add any other remarks from a like distinguished source.

The number of fish-plate bolts. — I have been led to say, that, no more importance should be attached to the abandonment of the three bolts on the Hanover lines, than to the condemnation of symmetrical switches on the Hungarian Railways (264).

It will be interesting to know what is taking place, on the Main-Weser lines.

I made use of three bolts from 1857 to 1860 on the Moulins line, and on the one from Bourges to Montluçon; and nothing to the disadvantage of this arrangement came under my notice. It was with regret that I abandoned it, in September 1861, to facilitate the adoption of the Vignoles rail on M. Morandières lines; so as to avoid two different arrangements of fish-plate holes, at the same Works (Aubin). Both my permanent way staff and myself regret it; as the three bolts greatly facilitated fixing four spikes at the joint sleepers.

Fish-plates, with the rails recessed for them. — In December 1857, this method was adopted, to reconcile the supposed facilities in rolling the rails with their being well fished. At that time, the Northern of France had only about 20 miles of line laid with the Vignoles rail; which rail, at the hands of the Orleans Railway Company, was met by many and powerful objections. Some feared, that with this rail the head might become detached; while the manager of our Works at Aubin saw considerable difficulties in rolling it. We therefore took advantage of the prestige attached to the Prussian Government rail, to firmly establish the Vignoles rail.

The recessing, a difficult operation to perform, has been attended with good results (see "Hannoverische Zeitschrift" 1861, p. 78); it has been applied successively, on both the main lines of the Limoges and Perigueux Railway. I only gave it up, through being further denounced as an innovator.

Modes of attachment. — On the central section of this Railway, the joint plate has never been made use of; for we held, that it increased the evils arising from the difference in height of badly gauged rails. No inconvenience through its not being used has been felt; though, it is true, that oak and beech sleepers alone have been employed.

The notches against the longitudinal slipping are placed at, or near, the middle of the rails; in order to reduce the amount of the oscillations caused by expansion, which unquestionably tend to the displacement of the spikes or screws.

I have never allowed the holes to be bored beforehand, on account of the extra width required in our numerous curves. The drills, not exceeding $\frac{3}{8}''$, should always be placed against the foot of the rail.

Bayonne line. — Whilst Engineer in charge of the Permanent way of the Southern of France Railway, I laid down and maintained the Bayonne section, until the year 1856. The "Brunel" rail used, differed from that of the Auteuil line, in having the sides of the foot rounded on the inner part, like the "Barlow" rail. I am disposed to think, that this tended largely to the formation of the numerous longitudinal cracks, in the head of the rails.

I did not notice any undulations caused by expansion, once the rails were fixed on the longitudinal sleepers.

Abandonment of the Barlow rail. — The Barlow rail was condemned by the Southern of France, as summarily, as when it was adopted; its defects were not in my opinion brought out. My views on the subject, at that time, are stated in the Hanover Review for 1855 and for 1856. Since then, the study of metallic longitudinals has suggested the following ideas.

Unless, with rails having an exceptional vertical resistance, as are those of Herr Hartwich (193) the weight of the locomotive is distributed, but very imperfectly. If the axle-load be 12 tons, each sleeper should be capable of bearing 12 tons; and even if the sleepers were kept nearer to one another, they would only be relieved, in proportion to the length of time they were subjected to strain, and not as to its intensity. Thus, a longitudinal sleeper system, may be considered as one where the cross sleepers touch one another throughout The "Barlow" rails ought, therefore, to be packed throughout, so as to be able to sustain at any point $\frac{12}{2}$, or 6 tons. This is, in reality a very difficult thing to obtain; and much more so, than to thoroughly pack a certain number of isolated points, the cross sleepers. In fact, so far, it has never yet been done.

Hence, arise constant deflections in the rails. The longitudinal cracks, which

destroy both the Barlow and the Brunel rails in precisely the same way, may they not be attributable entirely to these deflections? I am inclined to think so, and hence to infer a very unfavourable future for longitudinal supports in general, and more particularly as to composite ones. Herr Hartwich's very remarkable system seems to me, the only one, which may be excepted.

Stone blocks. — Stone blocks seem, singularly enough, to be once more in favour. Herr Buresch, informed me, two years since, that he intended to make use of them on the Oldenburg Railways; and Herr von Klein at Stuttgard somewhat astonished me, when he informed me, that the Wurtemburg Railway intended, if they had not already done so, to give a large order for some of them; as sleepers had risen greatly in price! Oak sleepers are nevertheless to be had there at a little over 4/' per sleeper; while the preparation of beech, abounding to excess in those forests, had not as yet been attempted.

Curves. —On the Central section of this Railway, rails of a length of 19'·6", alongside of the usual length of 19'·9", are used in curves. The length of 19'·6", adding to the number of exceptional rails, to which several other companies still adhere, appears to be a thoughtless tradition of the double-headed rail; where the previous adzing of the sleepers actually indicated a closer limit for the obliquity of the joints.

Curving the Vignoles rails, by their being allowed to fall, has been in practice on the Central section ever since 1861. It has answered very well.

On the Brenner line at the present time, on curves of 15 chains radius, a new description of saddle bedplate is being laid, three to each rail; they are provided with a downward longitudinal rib, let into the sleeper, to counteract transverse displacement. I have been unable to ascertain, if this novel arrangement has been founded on really substantial grounds.

ERRATA.

Page 20, line 8, from below *for* 16 tons. 2 cwt, *read* 15 tons. 12 cwt.
— 34, — 18, from below *for* June 12[th] *read* June 26[th].
— 49, — at bottom *after* line *add* (Pl. II, fig. 22).
— 65, — 8 and 7 from below *for* when locked *read* on the same axle.
— 68, — 7 ..... *omit* conical tyres,
— — — 8 ..... *omit* or rather.
— — — 8 ..... *insert* tyres *after* cylindro-conical.
— 80, — 15 from below *after* Pl. VI, fig. *read* 30.
— 85, — 3 ..... *after* $I = 0{\cdot}014{,}908{,}985$ *add* $\times 39{\cdot}37^2$.
— — — 5 ..... — $I = 0{\cdot}014{,}415{,}000$ — $\times 39{\cdot}37^2$.
— — — 7 ..... — $I = 0{\cdot}012{,}341{,}100$ — $\times 39{\cdot}37^2$.
— 89, — 12 ..... *for* section *read* sections.
— 105, — 13 from below *for* doubly *read* as in a couple.
— 112, — 17 from below *for* or *read* for
— 115, — 2 from below *after* $\frac{I'}{V'} = 0{\cdot}000{,}032{,}500$ *add* $\times 39{\cdot}37^3$.
— — — 3 from below *after* $\frac{I}{V} = 0{\cdot}000{,}142{,}500$ *add* $\times 39{\cdot}37^3$.
— 180, — 7 ..... *for* § III *read* § IV.
— 184, — 3 ..... *for* § IV *read* § V.
— 189, — 1 ..... *for* § V *read* § VI.
— 224, — 13 ..... *for* $\sqrt{2\rho\left(\frac{d^2}{8\rho}+j\right)}$; *read* $\sqrt{2\rho\left(\frac{d^2}{8\rho}+\frac{j}{2}\right)}$;
— 380, — 11 ..... *for* Permanent way *read* rolling stock.

Pl. XII, Scale to Figs 6, 7, 12, &c. is divided in error; it should be the same scale as for Fig. 22, Plate X.

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